Integration of Satellite Images and Census Data for Quality of Life Assessment in Hong Kong

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ABSTRACT

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Dynamic urban and economic development in Hong Kong has resulted in simultaneous up-grading and down-grading of quality of life (QOL) in different parts of the city. Assessment of spatial and temporal variations in quality of life is thus essential for policy makers to be alerted to problematic area and implement suitable preventive and remedial policies so as to maintain or sustain a reasonable quality of life. This study aims (1) to examine inter-relationship between the biophysical and socioeconomic factors; (2) to derive an integrative measure from the biophysical and socioeconomic factors for quality of life assessment and (3) to trace the spatial and temporal variation of quality of life in Hong Kong.

This study used two data types, i.e. biophysical data extracted from SPOT images acquired in 1991 and 1997 and from Landsat TM image acquired in 1996; and socioeconomic data extracted from 1991 census and 1996 by-census reports. All these data are at Tertiary Planning Unit (TPU) level, the basic unit used for population census. Multiple Linear Regression Modeling approach is adopted to examine the interrelationship between biophysical data and socioeconomic data. Principal component analysis (PCA) is used to derive quality of life indicators.

Regression modeling results illustrated that a significant negative relationship between population density and amount of vegetation cover is found. However, strong relationship was not found between other socioeconomic and biophysical variables.

Three QOL indicators are derived using PCA, they represent vegetation vigor, purchasing power and home ownership, which are positively related to QOL. Only the first indicator illustrates a general picture of QOL as it contains both biophysical and socioeconomic variables while other indicators imply the quality of socioeconomic aspect. Higher QOL is in rural areas as more green space and vegetation are preserved. In metropolitan areas, districts like the Mid-level, Kowloon Tong, the Southern District, and Happy Valley also experience a relative higher QOL where high-income group and upper middle-class are concentrated. New towns experience a higher QOL as new towns are planned with more green space. However, QOL for other urban areas are relatively lower. The major temporal changes in QOL are mainly found near new towns like Shatin, Yuen Long and Tin Shui Wai indicating that change of QOL is related to the new town development.

論文摘要

居民生活質素的變化是受到社會經濟及物理環境因素的影響，而生活質素的研究爲釐訂政策提供了基本數據。在過去的三十年中，香港經濟起飛，大規模的基建比比皆是，香港市民的生活素質因而有所改變。本研究旨在(1)探討社經及環境因素之間的相互關係，(2)建立一量度社區生活素質的指標，及(3)分析香港社區生活素質在時間及空間上的變化。

本研究採用兩組數據分析社區生活質素：(1) 透過衛星影像而攝取的環境數據，及(2)由統計年報中抽取所得的社會經濟數據。這兩組數據都是以「規劃統計小區」爲單位。此研究採用「線性逐步迴歸分析」及「主成分分析」分別探討社經及環境因素之間的相互關係和建立量度社區生活素質的指標。

線性逐步迴歸分析的結果顯示出只有植被覆蓋及人口密度有明顯的相對關係。主成分分析建立了三個生活質素指標，它們是植被，購買力及自置居所。只有植被指標可以建立一個結合社經及環境因素的生活質素指標，這個指標的主要成分包括植被覆蓋及人口密度，而植被覆蓋的影響是正面的，但人口密度的影響是負面的。購買力及自置居所皆對生活質有正面影響。

研究指出香港生活質素是與新市鎮建設及人口密度有關。從空間上的變化而言，沙田、天水圍、元朗等新市鎮的生活質素較市區爲好，市區中尤以人口密度低的九龍塘、半山區及南區等高尚住宅區生活質素較好。從時間上的變化而言，主要生活質素改變的地方在新市鎮及其鄰近地區。

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LIST OF ABBREVIATIONS

1991 SPOT	:	SPOT image acquired in 1991
1996 TM	:	Landsat TM image acquired in 1996
1997 SPOT	:	SPOT image acquired in 1997
A0-14	:	Percentage of population aged 0-14
A15-39	:	Percentage of population aged 15-39
A40-54	:	Percentage of population aged 40-54
A55+	:	Percentage of population aged 55 and above
BARED	:	Standard deviation of vacant development land
BAREM	:	Mean of vacant development land
BOTH_LAB	:	The proportion of economically active population in the total population aged 15 and over
$BPCA1_{91}$	:	Vegetation vigor in 1991
$BPCA1_{9197}$	:	Increase in diversity of vegetation
$BPCA1_{96}$	:	Soil brightness in 1996
$BPCA1_{97}$	:	Vegetation vigor in 1997
$BPCA2_{91}$	:	Diversity of vegetation in 1991
$BPCA2_{9197}$	:	Increase in vegetation vigor
$BPCA2_{96}$	:	Vegetation vigor in 1996
$BPCA2_{97}$	:	Soil brightness in 1997
$BPCA3_{91}$	:	Soil brightness in 1991
$BPCA3_{9197}$	:	Increase in soil brightness
$BPCA3_{96}$	:	Diversity of soil brightness in 1996
$BPCA3_{97}$	:	Diversity of vegetation in 1997
$BPCA4_{9197}$	:	Increase in vegetation vigor
$BPCA4_{96}$	:	Diversity of vegetation in 1996
$BPCA4_{97}$	:	Water area in 1997
$BPCA5_{9197}$	:	Diversity of urban area
$BPCA5_{96}$	:	Water area in 1996
$BPCA5_{97}$	:	Diversity of urban area in 1997
$BPCA6_{96}$	:	Surface temperature in 1996
ELEM	:	Percentage of elementary education level
F_LABOUR	:	The proportion of economically active female population in the total population aged 15 and over
GREEND	:	Standard deviation of greenness

GREENM	:	Mean of greenness
HH1	:	Percentage of household size 1
HH2	:	Percentage of household size 2
HH3	:	Percentage of household size 3
HH4	:	Percentage of household size 4
HH5	:	Percentage of household size 5
HH6	:	Percentage of household size 6 and above
INCOME	:	Median monthly household income
M_LABOUR	:	The proportion of economically active male population in the total population aged 15 and over
MARRY	:	Percentage of married population
NDVID	:	Standard Deviation of Normalized Differenced Vegetation Index
NDVIM	:	Mean of Normalized Differenced Vegetation Index
OWNER	:	Percentage of home ownership
PCA	:	Principal component analysis
POP_DEN	:	Population density
PROF_LAB	:	Percentage of professional working sector
QOL	:	Quality of life
QOL1-91	:	Degree of vegetation vigor in 1991
QOL1-9197	:	Increase in purchasing power
QOL1-96	:	Degree of vegetation vigor in 1996
QOL1-97	:	Degree of vegetation vigor in 1997
QOL2-91	:	Purchasing power in 1991
QOL2-9197	:	Decrease in vegetation vigor
QOL2-96	:	Purchasing power in 1996
QOL2-97	:	Purchasing power in 1997
QOL4-97	:	Home ownership in 1997
QOL5-9197	:	Increase in population density
QOL5-96	:	Home ownership in 1996
RVID	:	Standard deviation of Ratio Vegetation Index
RVIM	:	Mean of Ratio Vegetation Index
SAVID	:	Standard deviation of Soil Adjusted Vegetation Index
SAVIM	:	Mean of Soil Adjusted Vegetation Index
SEC	:	Percentage of elementary education level
SEX_RATIO	:	Sex ratio
SOILD	:	Standard deviation of soil brightness

SOILM	:	Mean of soil brightness
$SPCA1_{91}$	:	Purchasing power in 1991
$SPCA1_{9196}$	:	Increase in labour participation
$SPCA1_{96}$	:	Purchasing power in 1996
$SPCA2_{91}$	:	Working force in 1991
$SPCA2_{9196}$	:	Less educated population
$SPCA2_{96}$	:	Working force in 1996
$SPCA3_{91}$	:	Large household size in 1991
$SPCA3_{9196}$	:	Economic restructuring from secondary sector industry to tertiary sector industry
$SPCA3_{96}$	:	Large household size in 1996
$SPCA4_{91}$	:	Working age group in 1991
$SPCA4_{9196}$	:	Increase in purchasing power
$SPCA4_{96}$	:	Medium size family in 1996
$SPCA5_{91}$	:	Degree of crowdedness in 1991
$SPCA5_{9196}$	:	Increase in medium size family
$SPCA5_{96}$	:	Working age group in 1996
$SPCA6_{91}$	:	Home ownership in 1991
$SPCA6_{9196}$	:	Increase in female labour participation
$SPCA6_{96}$	:	Degree of crowdedness in 1996
$SPCA7_{9196}$	:	Decrease in children population
$SPCA7_{96}$	:	Home ownership in 1996
TEMPD	:	Standard deviation of surface temperature (°C)
TEMPM	:	Mean of surface temperature (°C)
TER	:	Percentage of elementary education level
TM1D	:	Standard deviation of TM1 (visible blue)
TM1M	:	Mean of TM1 (visible blue)
TM2D	:	Standard deviation of TM2 (visible green)
TM2M	:	Mean of TM2 (visible green)
TM3D	:	Standard deviation of TM3 (visible red)
TM3M	:	Mean of TM3 (visible red)
TM4D	:	Standard deviation of TM4 (near infrared)
TM4M	:	Mean of TM4 (near infrared)
TM5D	:	Standard deviation of TM5 (mid infrared)
TM5M	:	Mean of TM5 (mid infrared)
TM6D	:	Standard deviation of TM6 (thermal infrared)

TM6M	:	Mean of TM6 (thermal infrared)
TM7D	:	Standard deviation of TM7 (mid infrared)
TM7M	:	Mean of TM7 (mid infrared)
TPU	:	Tertiary Planning Unit
URBAND	:	Standard deviation of urban landuse
URBANM	:	Mean of urban landuse
VEGD	:	Standard deviation of vegetated area
VEGM	:	Mean of vegetated area
WATERD	:	Standard deviation of water area
WATERM	:	Mean of water area
WETD	:	Standard deviation of wetness
WETM	:	Mean of wetness
WORK2	:	Percentage of secondary working sector
WORK3	:	Percentage of tertiary working sector
XS1D	:	Standard deviation of XS1 (visible green)
XS1M	:	Mean of XS1 (visible green)
XS2D	:	Standard deviation of XS2 (visible red)
XS2M	:	Mean of XS2 (visible red)
XS3D	:	Standard deviation of XS3 (near infrared)
XS3M	:	Mean of XS3 (near infrared)
ΔA0-14	:	Changes in percentage of population aged 0-14
ΔA15-39	:	Changes in percentage of population aged 15-39
ΔA40-54	:	Changes in percentage of population aged 40-54
ΔA55+	:	Changes in percentage of population aged 55 and above
ΔBARED	:	Changes in standard deviation of vacant development land
ΔBAREM	:	Changes in mean of vacant development land
ΔBOTH_LAB	:	Changes in the proportion of economically active population in the total population aged 15 and over
ΔELEM	:	Changes in percentage of elementary education level
ΔF_LABOUR	:	Changes in the proportion of economically active female population in the total population aged 15 and over
ΔHH1	:	Changes in percentage of household size 1
ΔHH2	:	Changes in percentage of household size 2
ΔHH3	:	Changes in percentage of household size 3
ΔHH4	:	Changes in percentage of household size 4
ΔHH5	:	Changes in percentage of household size 5

Δ HH6	:	Changes in percentage of household size 6 and above
Δ INCOME	:	Changes in median monthly household income
Δ M_LABOUR	:	Changes in the proportion of economically active male population in the total population aged 15 and over
Δ MARRY	:	Changes in percentage of married population
Δ NDVID	:	Changes in standard deviation of Normalized Differenced Vegetation Index
Δ NDVIM	:	Changes in mean of Normalized Differenced Vegetation Index
Δ OWNER	:	Changes in percentage of home ownership
Δ POP_DEN	:	Changes in population density
Δ PROF_LAB	:	Changes in percentage of professional working sector
Δ RVID	:	Changes in standard deviation of Ratio Vegetation Index
Δ RVIM	:	Changes in mean of Ratio Vegetation Index
Δ SAVID	:	Changes in standard deviation of Soil Adjusted Vegetation Index
Δ SAVIM	:	Changes in mean of Soil Adjusted Vegetation Index
Δ SEC	:	Changes in percentage of elementary education level
Δ SEX_RATIO	:	Changes in sex ratio
Δ TER	:	Changes in percentage of elementary education level
Δ URBAND	:	Changes in standard deviation of urban landuse
Δ URBANM	:	Changes in mean of urban landuse
Δ VEGD	:	Changes in standard deviation of vegetated area
Δ VEGM	:	Changes in mean of vegetated area
Δ WATERD	:	Changes in standard deviation of water area
Δ WATERM	:	Changes in mean of water area
Δ XS1D	:	Changes in standard deviation of XS1 (visible green)
Δ XS1M	:	Changes in mean of XS1 (visible green)
Δ XS2D	:	Changes in standard deviation of XS2 (visible red)
Δ XS2M	:	Changes in mean of XS2 (visible red)
Δ XS3D	:	Changes in standard deviation of XS3 (near infrared)
Δ XS3M	:	Changes in mean of XS3 (near infrared)

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CHAPTER ONE INTRODUCTION

1.1 Conceptual Framework

In a development sense, sustainability is about maintaining and enhancing the quality of life while respecting the carrying capacity of the environment. In the last century, Hong Kong has evolved from a small fishing village to one of the highest concentration nodes of population and development densities in the world. As Hong Kong faces the challenge of accommodating up to two million people over the next 15 years with a limited territory of just over 1,098 square kilometers (Fung, 2000), maintaining and improving the quality of life is possibly the most pressing issue to be addressed in the twenty-first century. In his 1999 Policy Address which is titled "Quality People Quality Home", the HKSAR Chief Executive Tung Chee-wah addressed "achieving sustainable development and creating a first-rate living environment" (HKSAR Government, 1999 p.40) and "to make Hong Kong a clean, comfortable and pleasant home of which we are proud of" (HKSAR Government, 1999 p.42). In other words, it is important to improve the quality of life amidst the fast development in the 21st Century. The recent study "Sustainable Development for the 21st Century" (Planning Department, 2000) and "Hong Kong 2030 Planning Vision and Strategy" (Planning Department, 2001) have also stated that improving quality of life is one of the main criteria to maintain and upgrade Hong Kong's position in the world.

An important component in quality of life studies lies in the question of effective allocation of scarce resources (Megone, 1990). Territory of Hong Kong is about 1,098 square kilometers with more than 6.8 million inhabitants. Hong Kong is one of the most densely populated cities in the world with a population density of 6 310 persons per square kilometers in 2000 (Census and Statistics Department, 2001). Moreover, population has grown by approximately one million per decade over the past 20 to 30 years and it is expected to grow to around 8.3 million within 15 years (Planning Department, 1996). Given the limited land resources, policymakers need to find the most efficient way of distributing them in line with the needs and priorities of people. Moreover, quality of life has been strongly advocated as one of the three most important determinants of business location decisions by (Schmenner, 1982). High environmental quality, culturally desirable working and living conditions and convenient local amenities are believed to be vital to foster economic growth and job creation by retaining local business as well as attracting inward investment (Hall *et al.*, 1987; Bosman and M. de Smidt, 1993; Johnson and Rasker, 1995). Hence, it is clear to say that improving the quality of life is an important factor to maintain economic success of Hong Kong and consolidate Hong Kong's position as a World City.

Despite the importance of life quality study, there is no commonly accepted definition. Quality of Life (QOL) or simply life quality is dynamic and consists of both objective and subjective elements. Attributes defining life quality can be grouped into two clusters. These two clusters are associated with the biophysical environment and the socio-economic environment (Figure 1.1). And these clusters are interacting among each other to portrait a picture of QOL.

As Hong Kong is one of the most vibrant and dynamic cities in the world, the quality of life changes over time. Evolving from a small fishing village to one of the world's leading metropolises, many changes have taken place. From an economic perspective, quality and standard of living for Hong Kong citizens have been improved in the last few decades. Economic success, rising education level, improved living environment through rejuvenating inner city and adopting innovative approaches to the development of new towns help improve citizens' well being.

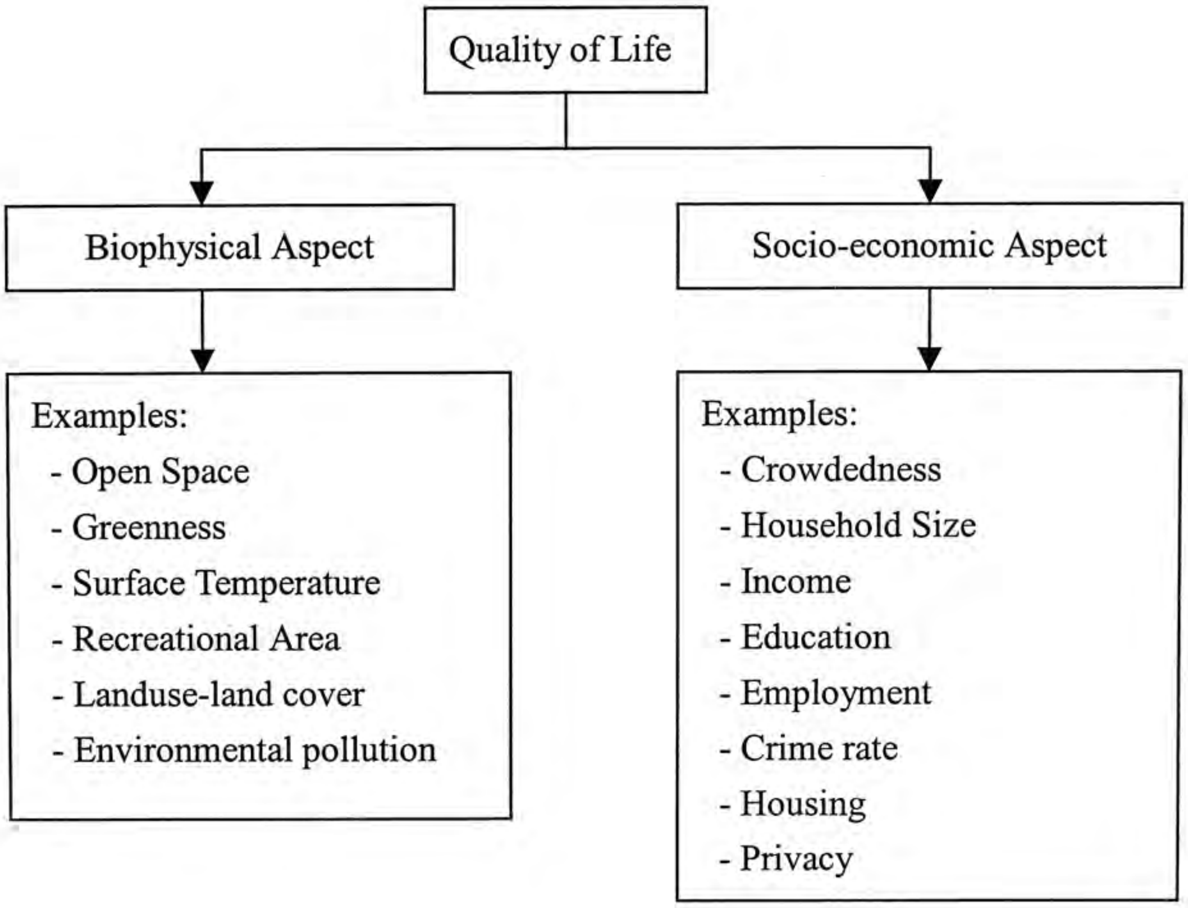


Figure 1.1 Structure of the life quality

From an environmental perspective, quality of life has degraded evidently from deteriorating air and water quality. Intensive development intrudes into ecological sensitive areas at the urban fringe like Long Valley and Sha Lo Tung. Meanwhile, multiple fast-tracking developments are in a close proximity to residences like West Rail construction works which produced nuisances to residents in Yuen Long, Tuen Mun and Kwai Chung (Mingpao, 2001a and 2001b). The key of projecting and improving life quality in the future lies on studying the current situation of quality of life.

Though quality of life study is essential for improving the citizens' well being, it is not an easy task because of the multi-dimensional nature of quality of life, financial consideration as well as the availability of data. The study should not only address present problems but also reveal past and current conditions to identify new opportunities that ensure a safe and healthy urban environment for the benefit and enjoyment for the present and future generations. Collecting data on socioeconomic variables and biophysical parameters can be cost-ineffective and time-consuming. The problem is especially acute in remote and relatively inaccessible areas. However, remote sensing provides useful information and analytical shortcuts for landuse planning and management as well as cost-effective environmental monitoring tool at a regional scale. Past experiences of applying image interpretation techniques on analyzing environmental changes have proven the potentiality of collecting biophysical data using remotely sensed imageries. For the socioeconomic environment, census data provide an ideal base. Territorial wide surveyed data include all variety of socioeconomic variables from population density, income, education level, to age and household size. Through integrating remotely sensed data and census data, a more complete picture of life quality can be drawn.

1.2 Objectives

The main purpose of this study is to investigate the use of integrated biophysical spectral indices and socioeconomic census data as indicators for studying quality of life in Hong Kong. More specifically, the objectives are:

(1) to examine the relationship between the biophysical and socioeconomic factors;

(2) to derive an integrative measure from the biophysical and socioeconomic factors for the quality of life assessment; and

(3) to trace the spatial and temporal variation of quality of life in Hong Kong.

This study reveals the conditions of quality of life over space and time, it also contributes to the assessment of policies and options under the principle of sustainability and hence aspiration for quality of life.

1.3 Significance

It is important to assess quality of life in an area for the past and current condition so as to identify problem areas and implement preventive and remedial measures to improve quality of life. The importance of urban quality of life study is highlighted as:

> Urban quality of life studies will increasingly become important tools for planning and managing livable, viable and sustainable cities. The quality of life studies results are now being used for purpose such as policy evaluation, rating of places and formulation of urban planning and management strategies. For urban planners, managers and policy makers, particularly in cities where citizens' quality of life is central to planning and policy decisions and processes, quality of life studies has proved invaluable.
>
> (Foo, 2001 p.1)

Moreover, quality of life is important to local economic development under the condition that the basic traditional factors such as land, human resources, infrastructure and capital are already in place (Wong, 2001). However, there is no previous study in Hong Kong that integrates socioeconomic and biophysical data for quality of life assessment in Hong Kong. Although similar research (Lo and Faber, 1997) has been done in western cities, it is doubtful if the same method can be applied in Asian cities. Therefore, there is a need to conduct a study that integrates socioeconomic data and biophysical data in Hong Kong or in other Asian cities.

On the other hand, providing timely and up-to-date quality of life result is important for policy making and development. Satellite images can provide up-to-date biophysical information for a large area efficiently and inexpensively. Census data are available in Hong Kong for every five years and provides socioeconomic data for study. Through integrating these two sets of data, it is hoped that up-to-date information about quality of life can be examined for the territory.

1.4 Study Area

Hong Kong (23°N 114°E) is located just within the tropics on the southern coast of China. It has a land area of 1098 km^2 and a sea area of 1823 km^2. The terrain is mountainous and rugged with very little flat land for settlement. Hong Kong's population is about 6.8 million with 94% of the population lives in urban areas in 2000 (Census and Statistics Department, 2001). Moreover, 51% out of this 94% population live in the metropolitan area (i.e. Hong Kong Island, Kowloon, New

Kowloon, Tsuen Wan and Kwai Chung). Figure 1.2 is a map of Hong Kong and its developed areas.

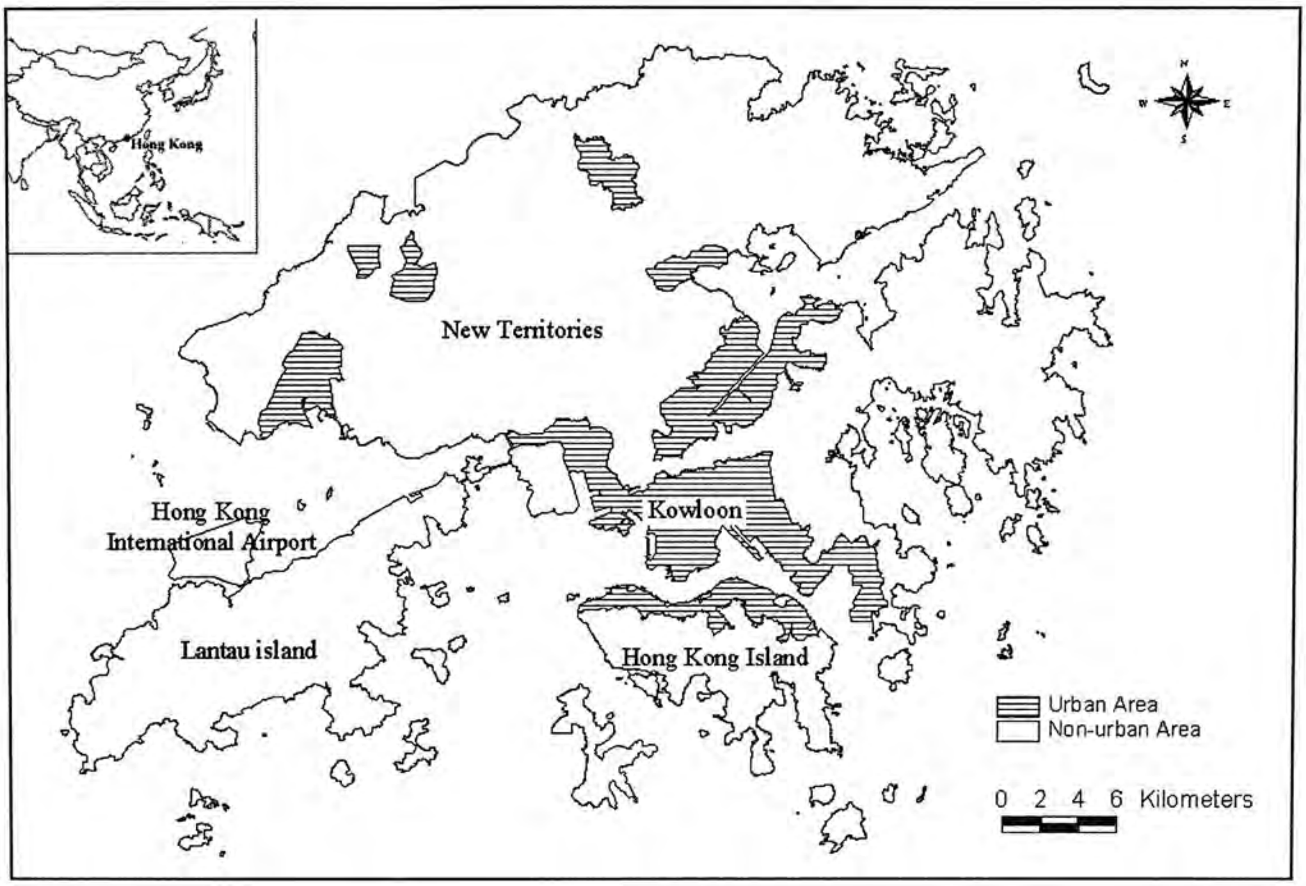


Figure 1.2 Map of Hong Kong

Hong Kong is a dynamic metropolis experiencing rapid urban development in the past 50 years. In the 1950s, Hong Kong was basically an entrepot. In the 1970s, she had evolved into a center of light manufacturing with textile and clothing accounted for 60 per cent of the export and employed 43 per cent of the workforce. Since the 1990s, Hong Kong has further developed into a world-class economic and financial center. In order to accommodate its ever-growing population and land demand from industries, reclamation has been taking place to gain more land for development. Parallel to reclamation, the Hong Kong Government adopts a high-rise and high-density development strategy as well as extends its footprint to the less developed New Territories. Construction of infrastructure, new town development, inner city renewal and real estate development are major active forces shaping and transforming the urban and rural landscapes. Despite her concentration on economic development, the pressure of urban development on the environment has alerted the community on issues related to dwindling green areas, air pollution and water quality determination etc. On the other hand, urban renewal has somehow created an opportunity to improve quality of life through better urban design and landscaping. Tree plantation in country parks, which occupy over 40% of the land territory, has given ample examples in environmental conservation.

1.5 Organization Of Thesis

This thesis is organized into seven chapters. A brief introduction on the needs of quality of life study in Hong Kong, objective, study scope and significance of this study is explained in Chapter One. A review of literatures on defining the life quality, application of remote sensing on urban areas and the use of remote sensing technique in quality of life studies are followed in Chapter Two. Chapter Three describes the methodology of integrating biophysical with socio-economic environmental factors and the quality of life mapping. Chapter Four explains the characteristics of the socioeconomic and biophysical data. Special focuses are placed over the interrelationship among the socioeconomic and biophysical variables using correlation and multiple stepwise regression models which are explained in Chapter Five. Quality of life indicators derived from principal component analysis are mapped and analyzed in Chapter Six. The conclusion, Chapter Seven, highlights the main findings and proposes the future research directions.

CHAPTER TWO LITERATURE REVIEW

This chapter reviews the literature concerning the nature and concept of quality of life (QOL), the development of QOL studies and the QOL indicators. Studies of applying remote sensing techniques on QOL studies and application of remote sensing in Hong Kong are also included.

2.1 Quality of Life and Indicators

2.1.1 Scope of Study for Quality of Life

Quality of life (QOL) has long been studied. Researchers from a variety of disciplines have studied QOL since the 1930s (Wish, 1986). They tried to identify the components of measuring QOL and compared various geographical areas like cities, states and nations by means of QOL indices they developed (Liu, 1976; Boyer and Savageau, 1981; Blomquist *et al.*, 1988; Stover and Leven, 1992; Sufian, 1993). An important reason for the interest in QOL lies in the question of effective allocation of scarce resources (Megone, 1990). World's population has reached 6.1 billion in the mid 2000 and the annual growth rate is 1.2% (United Nations, 2001). Policy makers need to find the most efficient way to meet the needs of present generation without compromising the ability of future generation to meet their own needs. The rise of the concept and theory of sustainable development strengthens the needs of QOL studies. Sustainable community can be defined broadly as one seeks to provide and maintain a good quality of life for all its community members (Shafer *et al.*, 2000). Through an interpretation of both biophysical and socioeconomic data, it is possible to evaluate the quality of life of a community on a continuing basis. This can help planners and government agencies engaged in the delivery of human services to be aware of any problem areas (Lo and Faber, 1997).

Despite the importance of QOL study, there is no general accepted definition of QOL. Wallace (1971), for example, defined QOL as

> "QOL includes the psychological and sociological dimensions of adequate housing, the enjoyment of cultural, recreation and leisure time activities; satisfying interpersonal relationships and health family functioning; the knowledge and resources to adapt to the changing times and an equal opportunity to influence the direction and speed of the change."
>
> (Wallace 1971 p.7)

Liu (1976) explained QOL as

> "the output of a certain production function of two but often interdependent input categories; physical inputs which are objectively measurable and transferable and the psychological inputs which are subjectively, ordinally differentiable but usually not interpersonally comparable."
>
> (Liu 1976, p.12)

Quality of life is concerned about the individual people and groups of people. It includes an individual's personal ambient environment (the setting for his daily living) and our shared global environment (including many 'green' issues) as well as the connections between these two dimensions. It is not as simple as an individual's concern in isolation (Seed and Lloyd, 1997). QOL certainly implies personal judgment. For instance, although per capita income is an objective measure, how satisfied people are about their income is subjective (Lo and Faber, 1997). Moreover, when a person says that he is satisfied, it may not mean that his living conditions are really improved (Lee, 1992).

Academicians from many different disciplines all agree that quality of life is multi-dimensional (Rowan, 1980). Maslow (1954) and McCall (1975) stated that QOL measurement should be based on the attainment of various basic needs of life such as food and shelter. Liu (1976) believed that QOL measurement should be based on economic, political, environmental, health, education and social factors. Schumaker, Anderson and Czajkowski (1990) simply regarded QOL as individual's overall satisfaction with life. Although there is no consensus, it is easy to find that there are three main approaches for QOL analysis, i.e. (1) subjective approach, (2) objective approach and (3) mixed subjective and objective approach (Naess, 1999).

Subjective approach involves perception, happiness and life satisfaction of individuals. In other words, it is about feeling good and being satisfied with living in general. It is often regarded as a micro level of measuring QOL. However, these components cannot be directly observed. Self-reports or interviews are needed to be conducted on individuals that involve a huge amount of efforts and resources (Naess, 1999).

Objective approach is usually applied in measuring the QOL of a community (Naess, 1999). It is about fulfilling the societal demands for social status and physical well being. This approach is regarded as a macro level of measuring QOL as it uses the objective status of biophysical and socioeconomic environment that a community lives in measuring QOL. Examples of the indicators include level of income and pollution level.

Mixed subjective and objective approach is frequently used in health-related research (Naess, 1999). Physical status and abilities, social interactions, economic status and factors and psychological well being are all involved in study (Spilker, 1990)

All the subjective, objective and mixed approaches involve biophysical and socioeconomic data. The total environment in which people live is determined by two main dimensions, namely morphological (biophysical) and socioeconomic environment (Chombart de Lauwe, 1952). Biophysical environment is made up of a landscape related elements such as landuse and land cover, air quality, soil and relief. It contributes to the QOL in two complementary ways: firstly, by directly providing such life supporting environmental ingredients as air and water; and secondly, by supplying the natural resources and through a human controlled production process, become valuable to humans (Collados and Duane, 1999). Socioeconomic environment represents the material infrastructure of social life such as income, education, employment and social facilities. The interaction of biophysical and socioeconomic environment affects the QOL. Biophysical and socioeconomic environment changes from time to time and varies from place to place. It is thus spatially and temporally dynamic. Therefore, a continuous study on QOL is essential to a community so as to find out the problem areas and make necessary improvement.

2.1.2 Development and Evolution of Quality of Life Studies

The contents and research agenda of Quality of Life studies are often developed in response to stimuli within the economic, social and political milieux in which researchers operate. There are three chronological stages in the evolution of QOL studies, namely 1960s, 1970s and 1980s, and recent development.

There is a shift of research focus of researches from 'standard of living' to 'quality of life' in the 1960s due to the improvement in material conditions of life in industrialized nations. Standard of living reflects the sufficiency in the quantity of necessities but quality of life refers to the qualitative well being of a community and the objective living condition (Tsang, 1996; Fischler, 2000). Due to a growing dissatisfaction amongst policy-makers with economic indicators such as GNP per capita and increased awareness of economic prosperity and growth in standard of living (Gross, 1966; Carley, 1981), there is a motivation of the development of such social indicators as employment, household income and leisure as part of QOL studies in the 1960s.

In the 1970s and 1980s, with a shift of focus to welfare economics and geography, QOL measurements become more important in the analysis of social and economic problems arising from inequalities in the distribution of welfare resources amongst different population groups (Rogerson, 1995). Liu (1976) firstly exemplified QOL research using census data to extract socioeconomic indicators. Bederman and Hartshorn (1984) used weighted socioeconomic variables extracted at the county level from the 1980 census data as a primary source to rank QOL in Georgia, USA. The increasing focus on QOL studies generates debate amongst researchers on who should be involved in the value judgements between alternative distributions of resources (Gehrmann, 1978).

Recent studies on QOL emphasizes on the subjective elements which reflect the focus on individual's external pressure and internal response. QOL is assessed by an individual's evaluation of the environmental conditions in which people live and the external circumstance of an individual's life (Lee, 1992; Shen, 1992; Foo, 2000). Day (1987) employed a subjective approach relating the level of satisfaction of the individual to each of his domains of life. These life domains include family life, material possessions, personal health, social life, spiritual life, shopping and consumption, working life and recreational life. Foo (2000) found that health and family life were more important indices than other aspects of life using 5-point Likert scale questionnaires in Singapore. These pieces of research, however, did not incorporate data on the biophysical environment for QOL assessment. It is believed that the inclusion of environmental data will provide a more comprehensive picture of QOL in light of concerns today about the air pollution, water pollution and natural conservation.

2.1.3 Quality of Life Indicators

How to measure the subjective and objective elements of QOL is the core of many academic studies. The most common practice is to develop indicators which is based on the belief that it helps incorporate a large amount of data into a few indices that can assist comparison and analysis. Table 2.1 summarized the QOL indicators used in selected previous studies. It is found that the most frequently used indicators include health care and medical services, environmental pollution,

Table 2.1 Frequency of life quality indicators used in literatures

	Subjective Approach											Objective Approach						Mixed Objective & Subjective Approach					
	Liu (1976)	Boyer & Savageau (1981)	Blomquist *et al.* (1988)	Wong (1991)	Lee (1992)	Shen (1992)	Stover & Leven (1992)	Sunday Times Supplement (1995)	Fadda & Jiron (1999)	Foo (2000)	Shafer *et al.* (2000)	Wingo (1973)	Amercian Chamber of Commerce in Hong Kong (1980)	Chow (1988)	Weber & Hirsch (1992)	Sufian (1993)	Wong (2001)	Boyer & Savageau (1985)	Offer (1996)	Lo (1997)	Lo & Faber (1997)	Seed (1997)	*Freq.*
Social Factors																							
- Population density								X							X	X				X	X		5
- Household ownership and value				X		X				X					X		X			X	X		7
- Housing Quality	X	X						X					X	X		X		X	X			X	9
- Household size										X			X						X				3
- Social life				X	X	X		X	X	X	X	X							X			X	10
- Leisure												X							X			X	3
- Education		X		X		X		X		X			X	X		X	X	X		X	X		12
- Privacy					X																		1
Economic factors																							
- Labour participation	X			X	X	X				X	X			X									7
- Income	X				X	X				X	X	X					X	X	X	X	X		11
- Percentage of professionals	X																						1
- Living cost																X		X	X				3
Community amenities																							
- Recreation	X	X							X	X	X			X									6
- Transportation				X				X	X	X	X			X		X		X				X	10
- Shopping & entertainment facilities					X				X		X		X	X									4
- Health care & medical services	X	X		X	X	X		X	X	X	X		X	X		X		X	X			X	15
- Church					X																	X	2
Politics	X					X																	2
Social problems																							
- Corruption						X																	1
- Crime rate	X	X	X	X			X	X								X		X					9
- Dependency population	X			X																			2
Biophysical environment																							
- Percentage of urban use			X				X				X									X	X		5
- Presence of greenness					X			X	X		X				X		X			X	X		8
- Surface temperature		X	X				X											X		X	X		6
- Environmental pollution	X		X	X	X	X	X	X	X		X	X				X			X				12

Social life - Friendship, community life, neighbourbood
Politics - Vote, election, participation in politic events
Freq. - Frequency of indicators used in listed literature
X - Indicators employed in corresponding studies

education, income, social life, presence of greenness, crime rate, transportation and household ownership and value. All these QOL indicators can be grouped into six classes including social factors, economic factors, community amenities, politics, social problems and biophysical environment. It is noted that socioeconomic variables are more frequently used than biophysical factors as in these QOL studies as socioeconomic variables are more direct and easier to obtain from existing reports like census report. However, in order to have a comprehensive picture of QOL, a balanced strategy of considering socioeconomic and biophysical environments should be used.

As mentioned in the previous section, there are subjective, objective and mixed subjective and objective approaches for studying QOL. From Table 2.1, it is found that most of the previous studies adopt the subjective approach which concerns the subjective well being of individuals.

The studies above were based on either qualitative and quantitative approaches. Since QOL and its indicators tend to be qualitative in nature, qualitative analysis is a more sounded study approach. Qualitative analysis basically employs research techniques such as interview and questionnaires to help answer the question "why" and provide greater understanding of the reasons behind quantitative trends and results. However, it is found that the sample size of those studies based on qualitative analysis are very limited. It is not difficult to understand that any in-depth interviews and questionnaires involve high time cost and human resources constraints. Hence, it is less applicable to regional studies. For example, it is difficult to interview the entire or just 50% of the entire citizen in Hong Kong in a two-year study period. Also, qualitative analysis often includes the consideration of indicators and factors that may not be easily quantifiable and thus difficult to present the findings. Thus, quantitative method is perfected if it is needed to study the QOL of a large area.

2.2 Quality of Life Studies using Remote Sensing data

2.2.1 Attributes derived from remote sensing

Remote sensing systems provide up-to-date and efficient spatial and temporal urban/ suburban attributes for analysis. Landuse and land cover, building and cadastral infrastructure, transportation infrastructure, utility infrastructure, Digital Elevation Model, socio-economic characteristics like population estimation and QOL, energy and production, meteorological data, critical environmental area assessment and disaster emergency response of an area can be extracted from remote sensing image (Jensen and Cowen, 1999). Moreover, degree of greenness and vegetation indices are important data that can be extracted from remote sensing systems. These data provide valuable information in revealing the status of biophysical environment in QOL studies.

2.2.2 Environmental changes and landuse change

The majority of more recent urban studies by applying remote sensing data are landuse and land cover change detection and analysis of heterogeneous landuse and land cover types. Change detection is a useful tool for determining the extent and nature of landuse and land cover changes through a comparison of images acquired of the same area at different times. Landuse and land cover changes can be enhanced by image overlay, image ratioing, image differencing and principal components analysis in which transformations of digital data help differentiate areas of changes from those of no change (Jensen, 1986; Pilon *et al.,* 1988). Thresholding techniques have been devised to depict the extent and areas of changes (Fung and LeDrew, 1988). Specific nature of landuse and land cover changes can also be acquired through image classification techniques such as spectral-temporal classification and post-classification comparison (Jensen, 1986). Most studies applying these change detection techniques tend to use images acquired by sensors of identical spectral, spatial and radiometric resolutions. Numerous works utilizing Landsat TM images for change detection had been reported (Jakubauskas *et al.,* 1990; Jensen, 2000).

2.2.3 Housing quality

Examples for integrating remote sensing data and socioeconomic data are usually used in housing quality studies.

Green (1957) made use of the Guttman Scale to combine several qualitative variables to form a "residential desirability scale" based on the physical data extracted from aerial photographs and a "socioeconomic status scale" based on census data. Landini and McLeod (1979) suggested "the discrimination of more categories of residential landuse would hold the greater benefit, particularly if this could be expanded to encompass an environmental quality and housing quality index" (p.80-81). Forster (1983) drew attention to the use of spectral reflectance data derived from Landsat MSS images in the city of Sydney, Australia to develop a residential quality index, using house size and vegetative content as a positive indicator of quality and roads and non-residential buildings as a negative indicator. Because house value is strongly related to house size, Forster (1983) has demonstrated that Sydney house values can be predicted from Landsat data over extended areas.

Inspired by Forster's (1983) work, Weber and Hirsch (1992) constructed three indices for Strasbourg's urban quality:

(1) a housing index which relates to the types of suburban housing;

(2) a quality index which measures the degree of housing density and greenness of the environment; and

(3) an attractiveness index which relates housing to the percentages of land cover in vegetation, industry, commerce and parking, solely extracted from the SPOT images.

These three indices were established through making use of the high-resolution SPOT XS (multispectral) image data in combination with cartographic and census data. In these studies, urban quality was expressed by means of scales or indices which combined the socioeconomic and physical data together for a complete evaluation. These two scales were found to be strongly correlated.

2.2.4 Integration of remote sensing data and census data

In order to draw a more complete picture on urban studies, integration of remotely sensed data with socioeconomic data becomes a trend. In the past, aerial photography was employed in conjunction with socioeconomic data from the census to measure the quality of the urban environment, typified by the work of Green (1957) and subsequently expanded on by Mumbower and Donoghue (1967) and Metivier and McCoy (1971) using a manual approach.

Applying NDVI to a study of quality of life in a county of Georgia, USA, Lo and Faber (1997) demonstrated that NDVI as a biophysical variable not only correlated to the percentage of urban landuse but also provided the linkage to socioeconomic data. QOL can be determined by giving both environmental and socioeconomic implications.

Conclusively, there are three approaches adopted to integrate the biophysical variable derived from remote sensing data with the socioeconomic variables: principal component analysis, GIS overlay and regression modeling (Richards, 1993). Principal component analysis (PCA) is a data transformation technique which can convert a large number of correlated variables into a small number of uncorrelated components made up of these variables, weighted according to the amount of the total variance for a series of sites, objects or person (Daultry, 1976). The GIS overlay approach integrates the biophysical and socioeconomic layers by a mathematically operations (Lo, 1997). Regression models are employed to derive the inter-relationship between biophysical and socioeconomic variables.

2.3 Quality of Life Study and Application of Remote Sensing in Hong Kong

Although the researches on the quality of life in Hong Kong were started in 1980s (Lau and Wan, 1987), there are only very limited researches on QOL have been conducted. In all researches on the QOL, a central concern is whether people are satisfied with their life. In other words, they focused on the psychological and sociological dimensions of individual's satisfactory.

Shen (1992) studied individual satisfactory of individuals to measure QOL using components like personal economic situation, confidence in government, job satisfaction and social status. Lee (1992) found that the respondents regarded health, spiritual well being, having friends, job satisfaction, good family life, privacy, getting along harmoniously with others and world peace as important criteria for a satisfying life in Hong Kong.

Researches of applying remote sensing technique on landuse and land cover studies in Hong Kong, however, are much more than QOL studies. Fung (1992 and 1997), Lulla and Rundquist (1997) used satellite imageries to study the urban expansion derived landuse and land cover changes. Analysis of heterogeneous land cover types using contextual measures was performed by Fung and Chan (1994). Interpreted from SPOT images, Yeh and Chan (1997) stated that the landuse and land cover changes in Hong Kong were closely related to the Territorial Development Strategy in 1984, Port and Airport Development Strategy in 1989 and the proliferation of open storage in the New Territories. Lo (1997) found that the image differencing method allows different categories of land cover changes to be detected in Hong Kong. For example, the technique has detected the intense activities of land reclamation in Hong Kong between 1987 and 1993 which lead to dramatically transformation of the configuration of the inner harbour.

In addition to landuse and land cover change detection, remote sensing techniques also applied in studying the environmental quality. Mean NDVI values derived from SPOT was integrated with 1991 census data at TPU level to examine the correlation between spectral data and socioeconomic factors (Fung and Siu, 2000). The generalized NDVI values mainly depicted the amount of green space in each TPU. Analyzing a time series data revealed significant reduction of green space in New Territories whereas improvement in green space was scattered in the urban core area indicating a better landscaping condition.

It is found that the existing studies using remote sensing focused on the physical aspects of landuse changes and spectral indices. However, these studies were seldom conducted in terms of their relationship with urban socioeconomic data as well as assessing quality of life in Hong Kong.

2.4 Summary

Although Quality of Life does not have a commonly accepted definition, there are three main approaches in the QOL studies, i.e. the subjective approach, the objective approach and the mixed subjective and objective approach. All these approaches involve biophysical and socioeconomic data. The most common way to derive QOL is to develop QOL indicators by incorporating a large amount of data into a few indices.

Remote sensing technique has been adopted to analyze QOL, environmental changes and quality, landuse changes and housing quality in recent years. For example, Lo (1997) and Fung and Siu (2000) have integrated both remote sensing studies and census data for QOL studies and environmental quality studies respectively. These studies found that remote sensing is a valuable technique to extract biophysical data for QOL studies.

CHAPTER THREE METHODOLOGY

As mentioned in the Chapter Two, quality of life (QOL) assessment should include both biophysical and socioeconomic data in order to acquire a comprehensive picture. Satellite imageries provide data for biophysical information while census reports provide data for socioeconomic characteristics. In this chapter, methodologies of employing satellite imagery data and census data for quality of life assessment are described. Description of satellite imagery data, census data processing and QOL indicator selection are also presented. A framework for integrating satellite imagery data with socioeconomic data is explained.

3.1 Data Description

QOL in this study is expressed by means of indices that combine the socioeconomic and biophysical data for a complete evaluation. Socioeconomic data is based on census report whilst biophysical data is extracted from satellite imageries. Figure 3.1 illustrates the procedures used to derive and interpret these data for analysis.

3.1.1 Biophysical data

Biophysical data refer to elements of the physical environment. Examples are greenness, air quality, noise pollution, environmental temperature, landuse and land cover, topography and water quality. Jensen and Cowen (1999) have cited that biophysical data like landuse and land cover, surface temperature and urban heat island effect can be observed in satellite images. However, data like air quality and

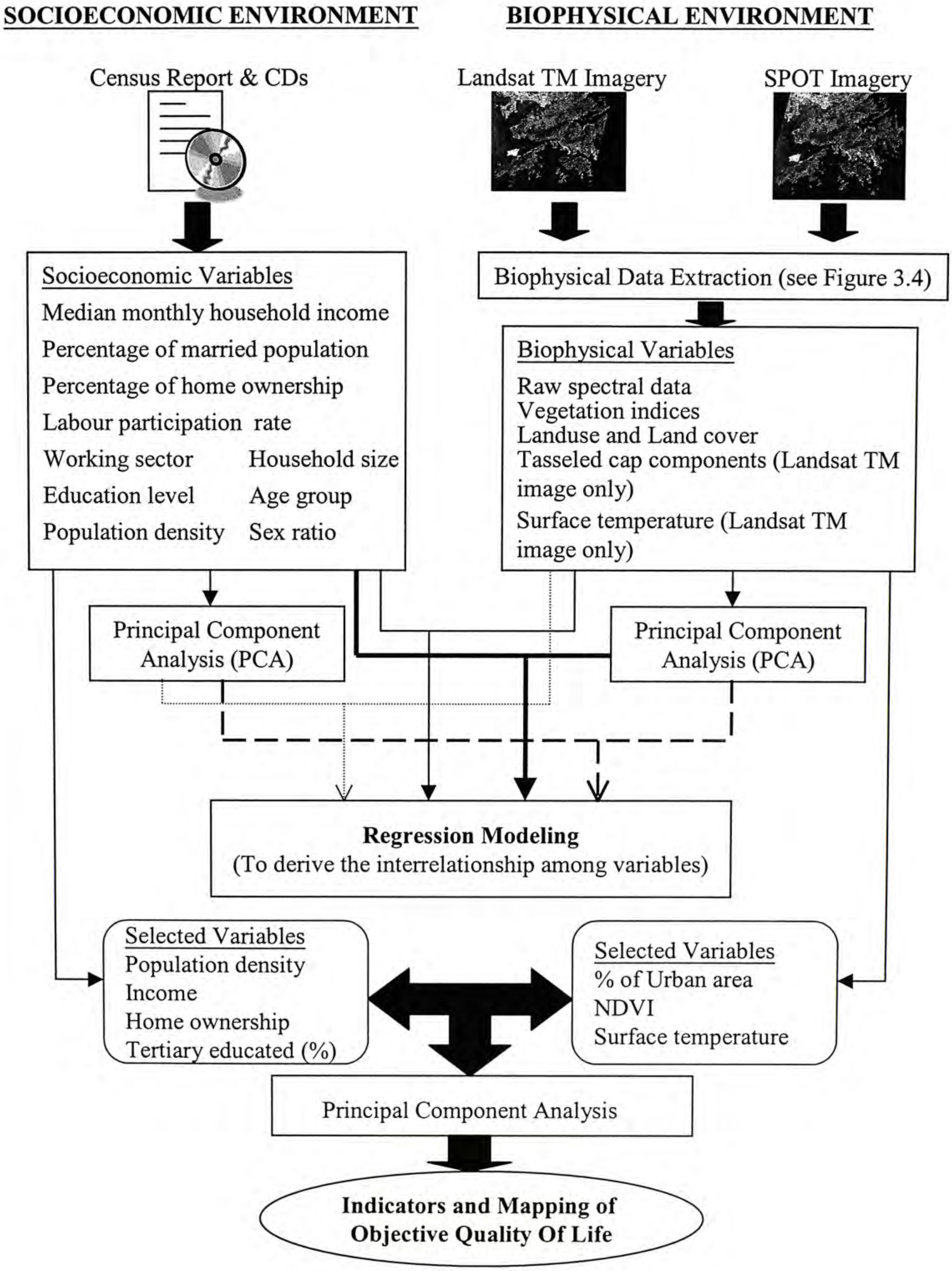


Figure 3.1 Flowchart showing the procedures of deriving QOL indicators

noise pollution cannot be directly interpreted and collected from satellite images. Hence, extractable biophysical variables like raw spectral data, vegetation indices, landuse and land cover, surface temperature and tasseled cap components are used for quality of life study only. In the interpretation process, both mean and standard deviation of these biophysical variables are determined. Standard deviation of biophysical data represents the diversity of the data. It is due to the variations within that data or the mixing with other landuse and land cover type in a TPU. For example, diversity of vegetation is due to different vegetation types and the mixing with other landuse and land cover types. Details of these variables are described below:

Raw spectral data refers to spectral band XS1, XS2 and XS3 from SPOT and TM1, TM2, TM3, TM4, TM5, TM6 and TM7 from Landsat TM;

(1) Vegetation indices include Normalized Difference Vegetation Index (NDVI), Ratio Vegetation Index (RVI) and Soil Adjusted Vegetation Index (SAVI);

(2) Landuse and land cover includes urban landuse, vacant development land, vegetation cover and water area;

(3) Tasseled cap components include soil brightness, greenness and wetness. Soil brightness represents bare soil, greenness represents vegetation vigor and wetness represents high soil moisture content; and

(4) Surface temperature affects comfort of the people which in turn affects quality of life.

Tasseled cap components and surface temperature are extracted only from TM image. Details of these biophysical variables are listed in Table 3.1.

Table 3.1. Biophysical data extracted from the Landsat TM and SPOT imageries.

Biophysical Variables		Sensor	Abbreviation*
Raw Spectral Data	XS1 (visible green)	SPOT	XS1
	XS2 (visible red)	SPOT	XS2
	XS3 (near infrared)	SPOT	XS3
	TM1 (blue)	TM	TM1
	TM2 (green)	TM	TM2
	TM3 (red)	TM	TM3
	TM4 (near infrared)	TM	TM4
	TM5 (mid infrared)	TM	TM5
	TM6 (thermal infrared)	TM	TM6
	TM7 (mid infrared)	TM	TM7
Vegetation Indices	Normalized Vegetation Index	SPOT & TM	NDVI
	Ratio Vegetation Index	SPOT & TM	RVI
	Soil Adjusted Vegetation Index	SPOT & TM	SAVI
Landuse and Land Cover	Urban landuse	SPOT & TM	URBAN
	Vacant development land	SPOT & TM	BARE
	Water area	SPOT & TM	WATER
	Vegetation cover	SPOT & TM	VEG
Tasseled Cap Components	Soil brightness	TM	SOIL
	Wetness	TM	WET
	Greenness	TM	GREEN
Surface Temperature (°C)		TM	TEMP

* A letter "M" is added to the end of every abbreviation of biophysical variable representing the mean of spectral reflectance for these variables. For example, NDVIM represents mean of NDVI. Similarly, a letter "D" is added to the end of every abbreviation of biophysical variable representing the standard deviation of spectral reflectance for these variables.

3.1.2 Socioeconomic data

Socioeconomic data depict both the demographic and the socio-cultural environment. These data are extracted from the 1996 by-census report and CD-ROM (Census and Survey Department, 1996) and report of the 1991 Census (Census and Statistics Department, 1991). Totally, twenty-four socioeconomic variables are extracted for each year and they are shown in the Table 3.2.

It is an established practice in Hong Kong since 1961 to conduct a population census every ten years and a by-census in the middle of intercensal period (Census and Statistics Department, 1996). The 1991 Population Census comprised a 100% enumeration of all persons by age and sex and an one-in-seven sample enquiry on detailed demographic and socio-economic characteristics of the population. All households were enumerated during the ten-day period from 15 to 24 March 1991 (Census and Statistics Department, 1991). The 1996 Population By-census was conducted during the period from 16 to 24 March 1996. About one-seventh of all quarters in Hong Kong were sampled and all households therein were included in the enquiry (Census and Statistics Department, 1996).

The *de facto* enumeration approach was adopted in the 1991 Population Census. All persons who were present or temporarily away from Hong Kong were enumerated. However, detailed questions on demographic and socio-economic characteristics were only conducted on residents present in Hong Kong during the enumeration period. As more residents were temporarily away from Hong Kong, the *de jure* enumeration approach was adopted in the 1996 Population By-census.

Table 3.2. Socioeconomic variables extracted from the census reports.

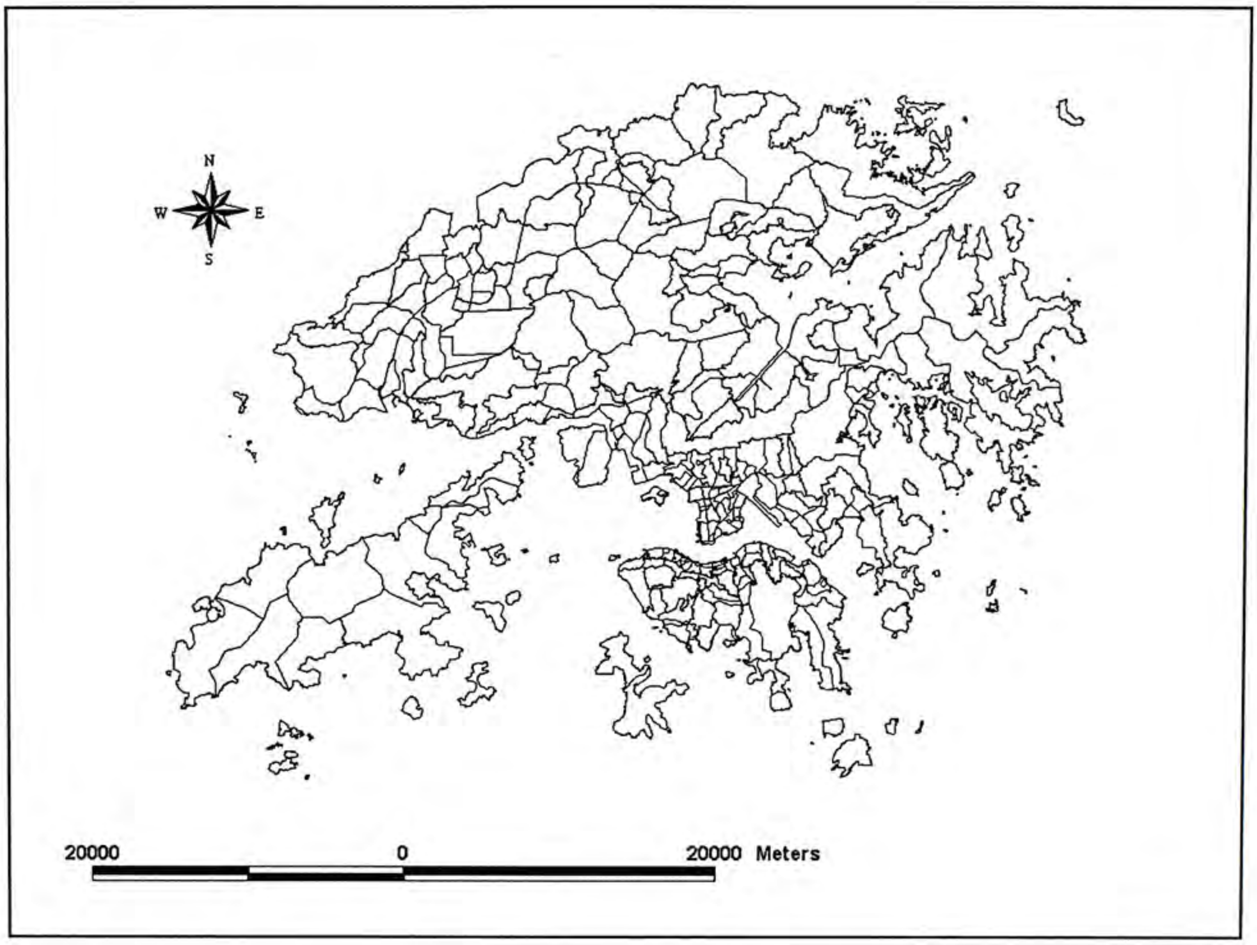
Socioeconomic variables		**Abbreviations**
Population density		POPDEN
Median monthly household income		INCOME
Sex ratio		SEX
Percentage of home ownership		OWNER
Percentage of married population		MARRY
Education level	Percentage of elementary education level	ELEM
	Percentage of secondary education level	SEC
	Percentage of tertiary education level	TER
Household size	Percentage of household size 1	HH1
	Percentage of household size 2	HH2
	Percentage of household size 3	HH3
	Percentage of household size 4	HH4
	Percentage of household size 5	HH5
	Percentage of household size 6 and above	HH6
Age group	Percentage of age 0-14	A0-14
	Percentage of age 15-39	A15-39
	Percentage of age 40-54	A40-54
	Percentage of age 55 and above	A55+
Working sector	Percentage of secondary working sector	WORK2
	Percentage of tertiary working sector	WORK3
	Percentage of professional working sector	PROF_LAB
Labour participation	The proportion of economically active male population in the total population aged 15 and over	M_LABOUR
	The proportion of economically active female population in the total population aged 15 and over	F_LABOUR
	The proportion of economically active population in the total population aged 15 and over	BOTH_LAB

Members of household who usually lived in Hong Kong in the six-month period either before or after the reference moment was counted. Those who usually worked in Mainland China or Macau were all enumerated and asked of their detailed demographic and socio-economic characteristics. A person was enumerated in the household and quarters where he was found at the reference moment and treated as a member of that household. On the other hand, any members of that household who were temporarily away from Hong Kong or were not staying in their own household but in other places of accommodation in Hong Kong at the reference moment were excluded (Census and Statistics Department, 1996).

3.1.3 Data extracted at Tertiary Planning Unit

All the biophysical and socioeconomic data are extracted at Tertiary Planning Unit (TPU) level which is the basic unit used for population census and planning purpose in Hong Kong. The whole territory was divided into 274 and 276 Tertiary Planning Units in 1991 and 1996 respectively (Figure 3.2). These TPUs were aggregated under 51 Secondary Planning Units (SPU) at the next higher level. The SPUs were further grouped under 9 Primary Planning Units (PPU) at the highest level. Each TPU can be identified by a three-digit number. The first digit corresponded to the PPU code, the first and second digits together corresponded to the SPU code. For 1991 census and 1996 by-census, population at the TPU level referred to people living on land only, i.e. people enumerated on board marine vessels are excluded (Census and Statistics Department, 1991 and 1996). In 1991, areas with small population size were excluded from census and these TPUs are regarded as having missing data during the analysis.

a)TPUs in 1991



b)TPUs in 1996

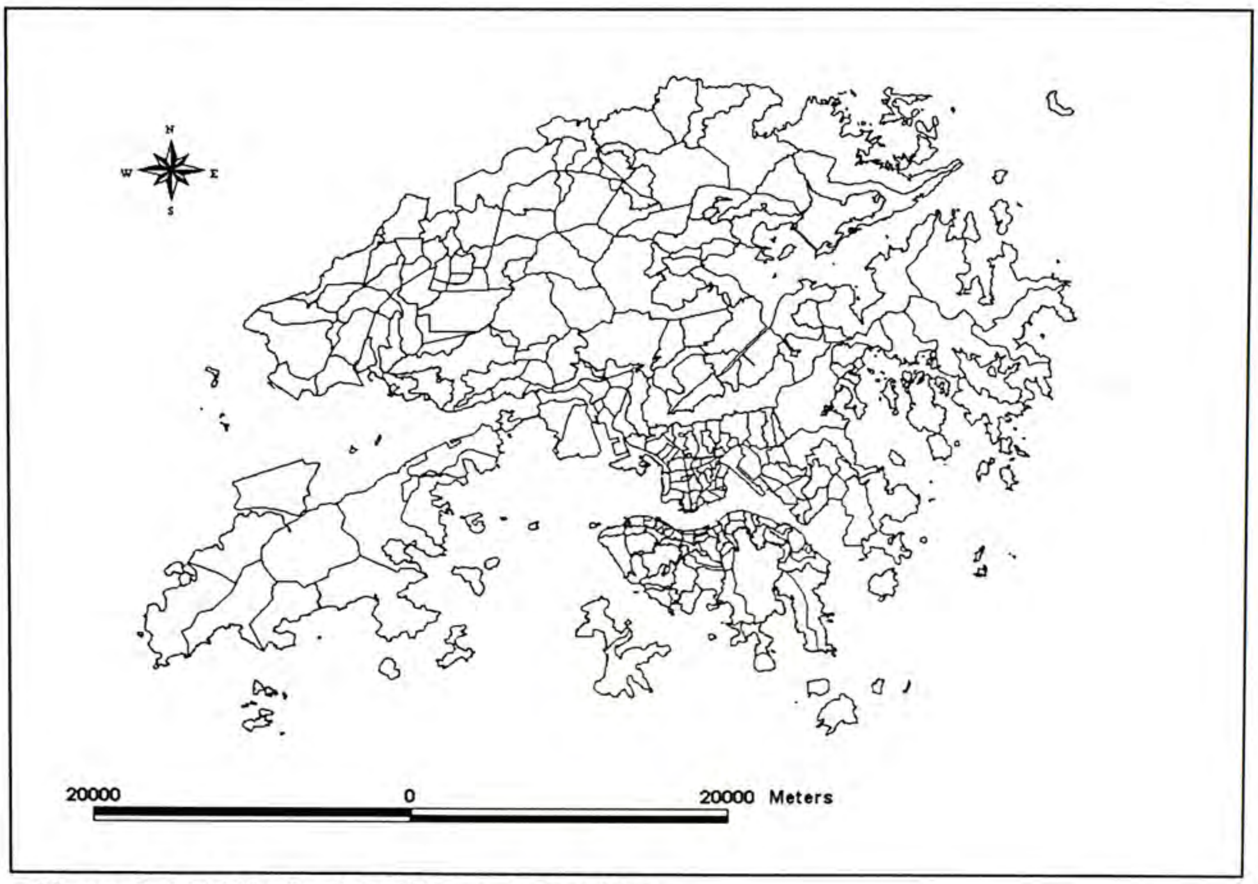


Figure 3.2 TPUs for (a) 1991 and (b) 1996.

The TPUs for 1991 and 1996 are not the same. Significant differences are found in coastal areas where reclamation is active. Under the effect of reclamation, i.e. change from seawater to construction sites, areas with increasing land are found in western Kowloon, Chek Lap Kok and Kwai Chung.

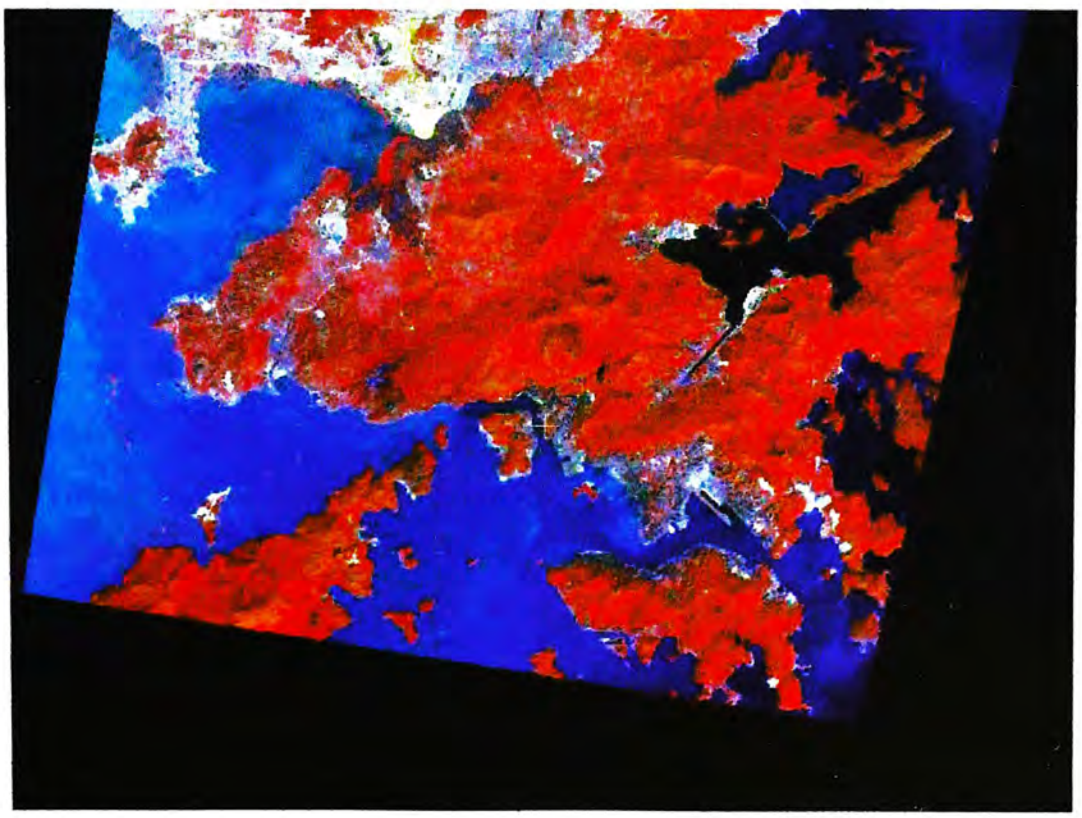
Data extracted for this study do not include all the most commonly used QOL indicators as illustrated in Table 2.1 of the Chapter Two. It is because some of these data are not available in census or satellite images at the TPU level. For example, crime rate, privacy, environmental pollution and proximity to community services are not included in this study.

Data extracted from the censuses are grouped into few uncorrelated variables using Principal Component Analysis for easier interpretation. Principal Component Analysis attempts to identify underlying variables or factors that explain the pattern of correlations within a set of observed variables. It is often used in data reduction to identify a small number of factors that explain most of the variance observed in a much larger number of manifest variables (SPSS, 1999). The statistical package of SPSS is used to perform principal component analysis.

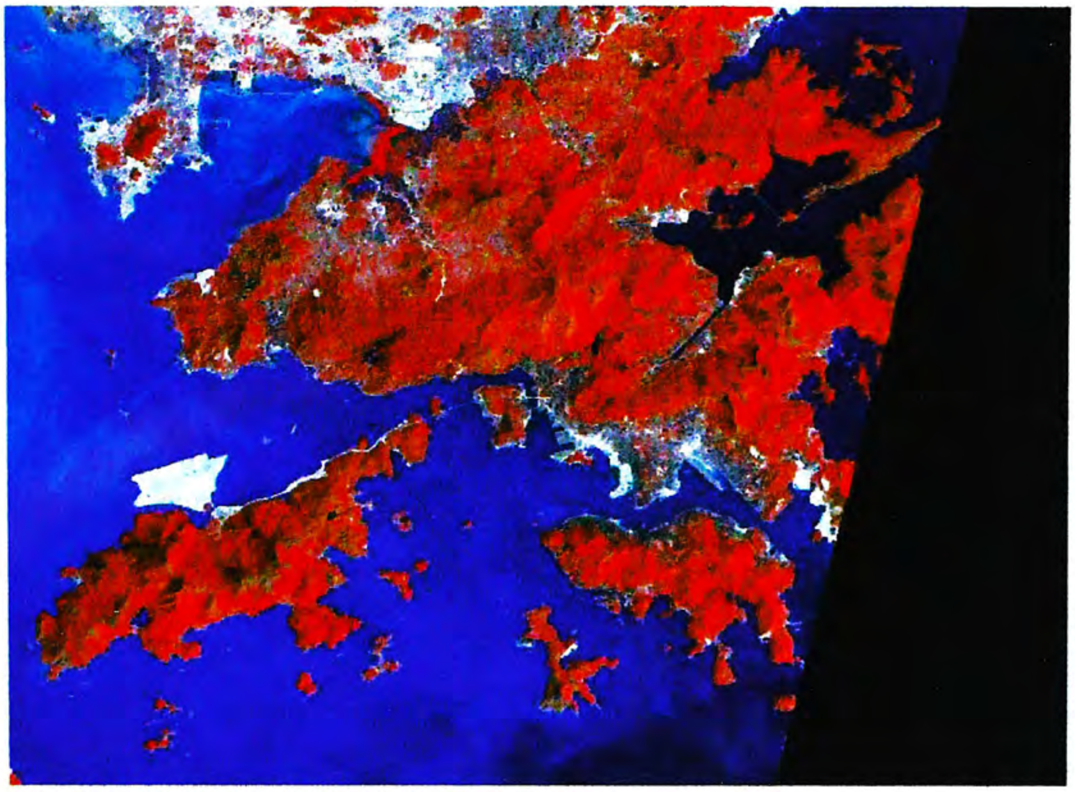
3.2 Satellite Data Preprocessing

Two SPOT High Resolution Visible (HRV) images and one Landsat TM image are utilized in this study. SPOT HRV imageries used were acquired on December 21, 1991 and January 29, 1997 with 20-meter spatial resolution. They were all acquired during winter when the dry monsoon prevailed. The Landsat-5 image was acquired on March 3, 1996 with 30-meter spatial resolution and 120-meter resolution for the thermal infrared band (TM6) (Figure 3.3). Both images were acquired during cloudless and sunny day (Hong Kong Royal Observatory, 1991, 1996 and 1997). Although none of the images cover the entire territory of Hong Kong, they do not affect the study as those missing parts of the imageries are found in remote areas with small population in Hong Kong. TPU covering these areas are regarded as missing data during the analysis. Table 3.3 illustrates the spectral data of the two satellite sensors and Table 3.4 lists the scene specifications of the three images. The multi-spectral data are processed using the PCI Geomatics version 7.0 image processing package with a NT 4.0 Workstation. Figure 3.4 illustrates the flowchart of procedures of image processing for biophysical data extraction.

a) 1991 SPOT image



b) 1996 TM image



c) 1997 SPOT image

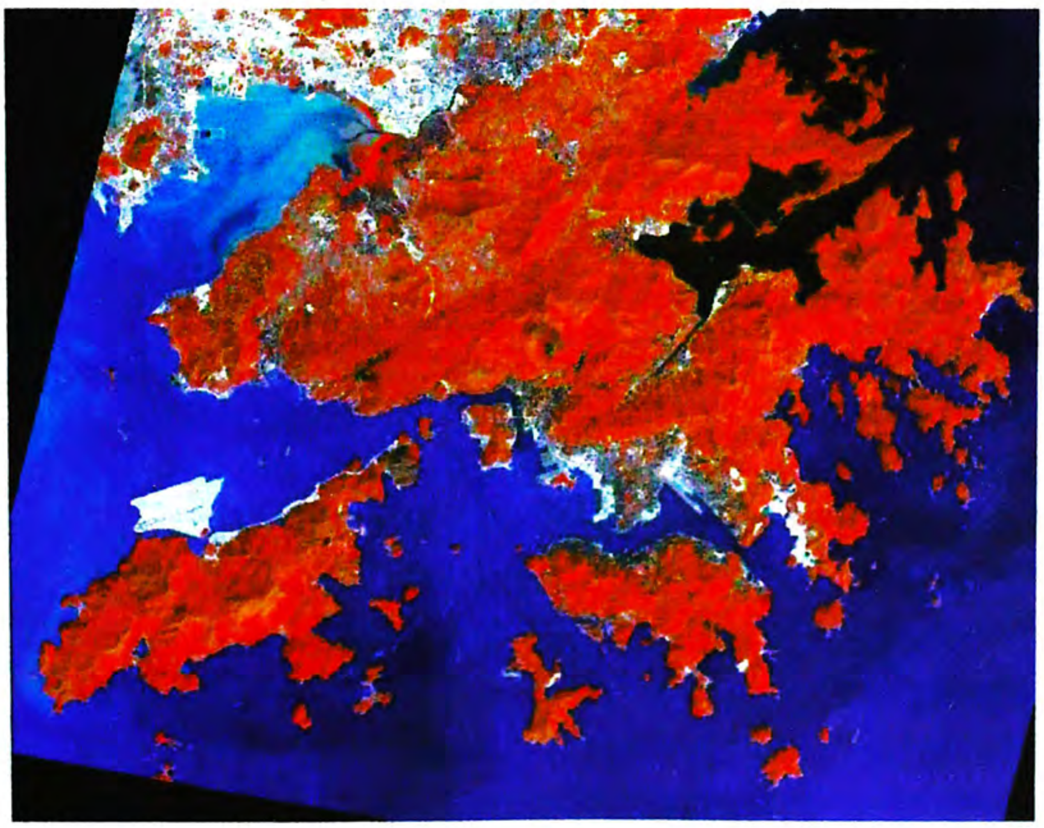


Figure 3.3 The SPOT and Landsat TM imageries for Hong Kong.

Table 3.3 Spectral characteristics of the bands of (a) SPOT HRV and (b) TM imageries.

(a) SPOT HRV

Band	**Spectral band (μm)**	**Spatial Resolution (m)**	**Description**
XS1	0.50 – 0.59	20	Visible Green
XS2	0.61 – 0.68	20	Visible Red
XS3	0.79 – 0.89	20	Near infrared

(b) TM image

Band	**Spectral band (μm)**	**Spatial Resolution (m)**	**Description**
TM1	0.45 – 0.52	30	Visible Blue
TM2	0.52 – 0.60	30	Visible Green
TM3	0.63 – 0.69	30	Visible Red
TM4	0.76 – 0.90	30	Near infrared
TM5	1.55 – 1.75	30	Mid-infrared
TM6	10.4 – 12.5	120	Thermal infrared
TM7	2.08 – 2.35	30	Mid-infrared

Table 3.4 Scene specification of the SPOT and TM images.

Satellite Name	SPOT2	Landsat 5	SPOT2
Instrument Mode	HRV1	Thematic Mapper	HRV1
Level	1B	--	1A
Date of acquisition	91/12/21	96/03/03	97/01/29
Time of acquisition	110541	--	111912
Sun elevation	40.6	42.0	45.5
Azimuth (degree)	157.0	123	153.3
Incidence angle (degree)	R7.0		L23.0
Scene center longitude (DMS)	E 1140406	E 1133025.2116	E1140642
Scene center latitude (DMS)	N 0223030	N 224452.7496	N0222409
Gain factors (gain/ bias) Or Gain number (abs cal gain)	XS1: 6 (01.03890) XS2: 7 (01.15744) XS3: 5 (01.28655)		XS1: 8 (0.39100) XS2: 8 (0.35000) XS3: 6 (0.697000)

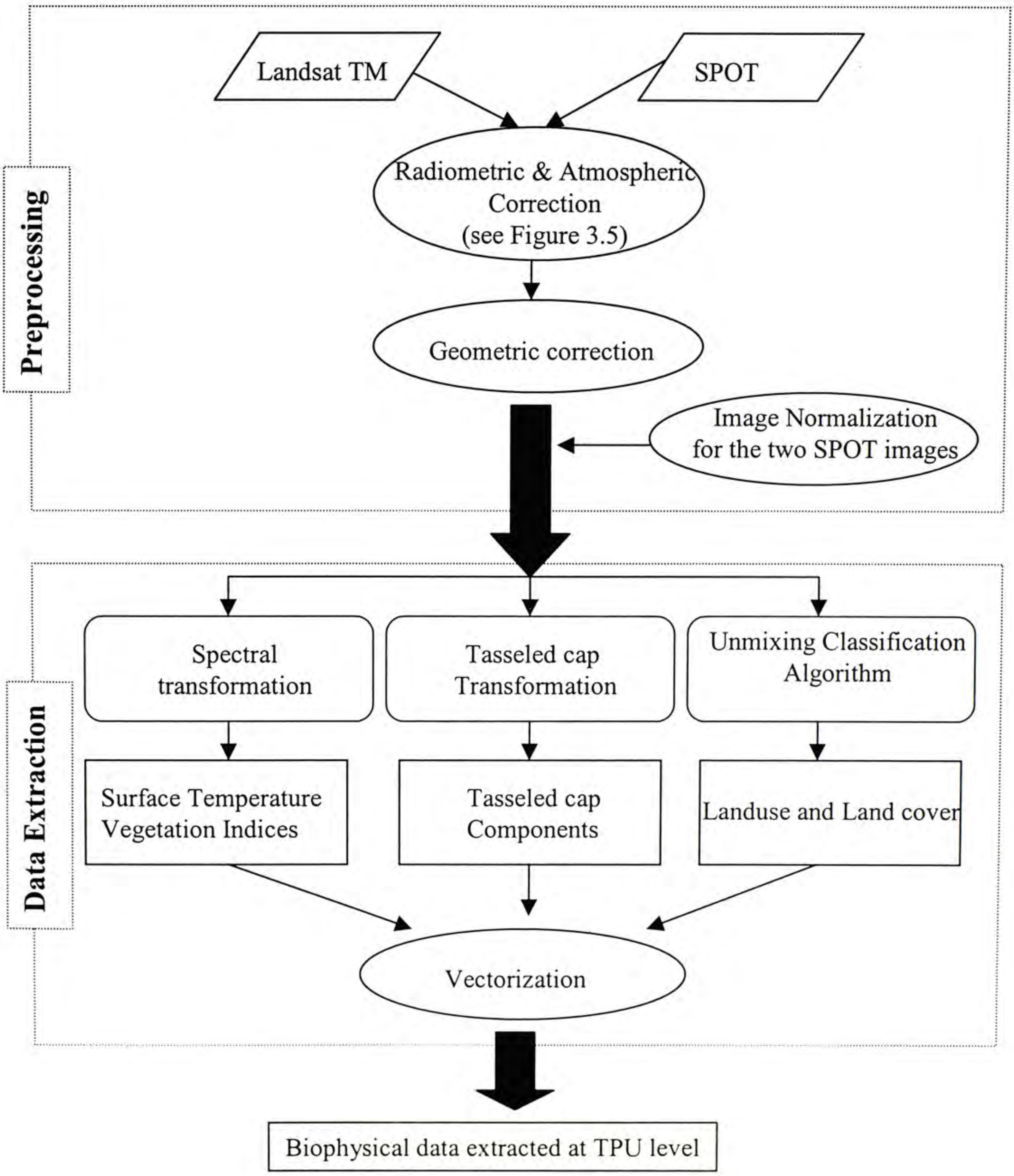


Figure 3.4 A flowchart of procedures of image processing and biophysical data extraction

3.2.1 Radiometric and atmospheric correction

Satellite data acquired by Landsat TM and SPOT are stored in digital numbers ranging from 0 to 255 which do not have a physical meaning. Therefore it is necessary to convert the digital numbers into physical reflectance for Landsat TM and physical radiance for SPOT. Radiometric correction requires several levels of calibration, including sensor calibration, atmospheric correction, solar and topographic correction. Figure 3.5 illustrates the procedures of radiometric and atmospheric corrections so as to calibrate the digital values of remote sensing data to surface reflectance. Data extracted from Landsat TM image are used to study their applicability on QOL studies as well as their relationship with socioeconomic variables but not directly compared to SPOT data in statistical value.

For TM image, at-sensor calibration using calibrations gains (cal_gain_b) and offset (cal_offset_b) measured preflight are shown in Table 3.5. These coefficients can be applied to TM pixel values in each band DN_b using Equation 3-1 (Schowengerdt, 1997).

$$L_\lambda = cal\_gain_b \bullet DN_b + cal\_offset_b \qquad (3-1)$$

At-satellite planetary reflectance for TM1, TM2, TM3, TM4, TM5 and TM7 are extracted for reducing between-scene variability through normalization of solar irradiance by converting spectral radiance calculated to effective at-satellite reflectance or in-band planetary albedo. This combined surface and atmospheric reflectance of the Earth is shown in Equation 3-2 (Markham and Barker, 1986).

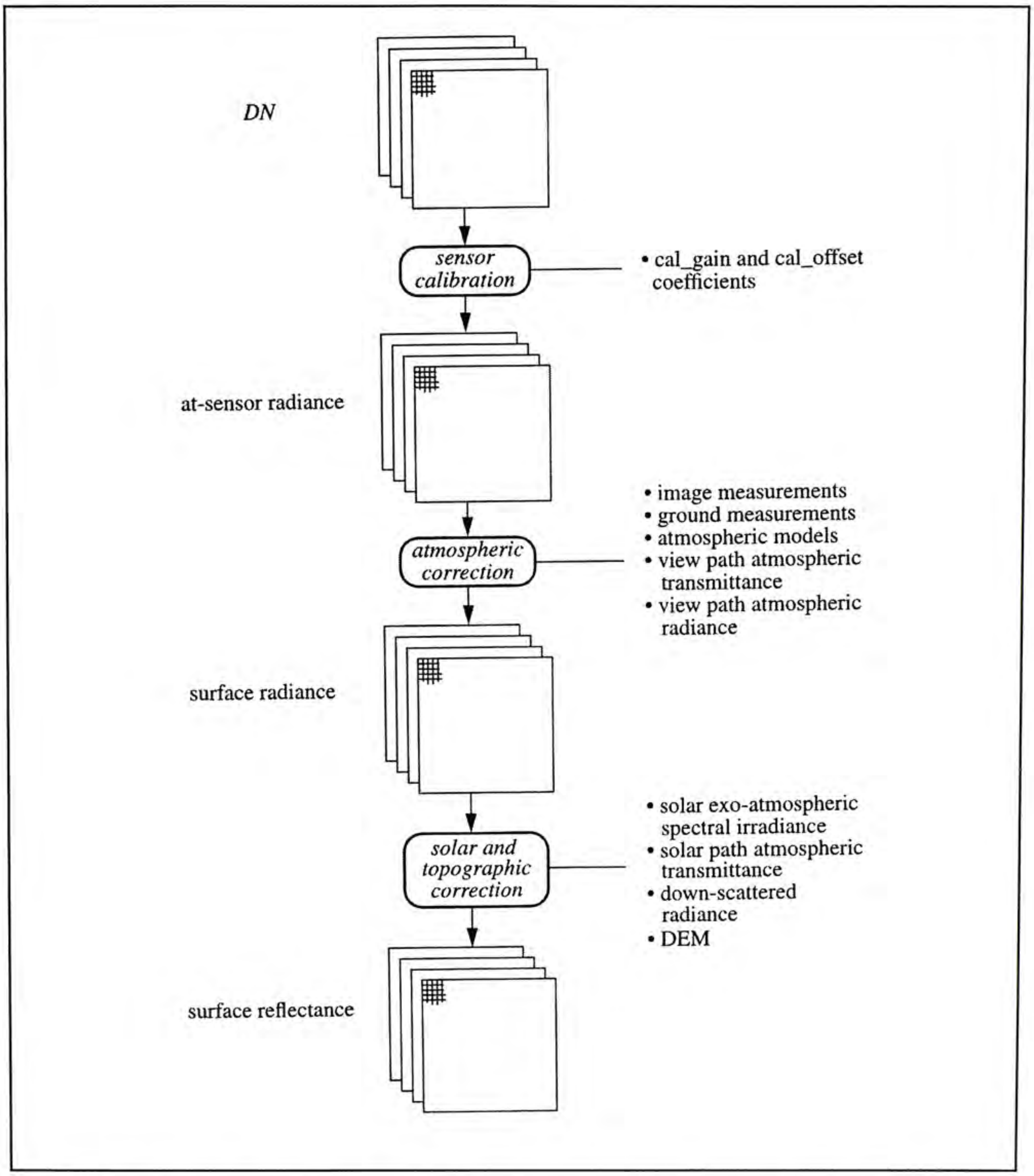


Figure 3.5 Procedures of radiometric and atmospheric corrections (Schowengerdt, 1997, p.312)

Table 3.5 Pre-flight measurements of the TM calibration gain and offset coefficient. (Gains are in radiance/DN units and offset is radiance with units mW-cm^{-2}-sr^{-1}-μm^{-1}).

Satellite	Landsat 5	
Band	Cal_gain	Cal_offset
1	0.642	-2.568
2	1.274	-5.098
3	0.979	-3.914
4	0.925	-4.629
5	0.127	-0.763
6	0.0552	1.238
7	0.0677	-0.0338

Source: EOSAT (1993), cited in Schowengerdt (1997)

$$Pp = \frac{\pi \bullet L_\lambda \bullet d^2}{ESUN_\lambda \bullet \cos\theta s} \quad (3-2)$$

where

Pp = Unitless effective at-satellite planetary reflectance (i.e. surface radiance)

L_λ = Spectral radiance at sensor aperture in mW•cm^{-2}•ster^{-1}•μm^{-1} from equation 3-1

d = Earth-Sun distance in astronomical units

$ESUN_\lambda$= Mean solar exoatmospheric irradiances in mW•cm^{-2}•ster-1•μm^{-1}

θs = Solar zenith angle in degrees

The Earth-Sun Distance can be calculated using the Equation 3-3. Eccentricity correction factor of the earth's orbit (E_o) is 1.018 AU for 3 March, 1996 (Iqbal, 1983).

$$E_o = (d_o/d)^2 \quad (3\text{-}3)$$

where

Eo = Eccentricity correction factor of the earth's orbit

d_o = Mean Earth-Sun Distance (1AU)

d = Earth-Sun Distance in Astronomical Unit(AU)

Solar and topographic correction requires the surface radiance, solar path atmospheric transmittance, exoatmospheric solar spectral irradiance and the incident angle (Schowengerdt, 1997). Due to the missing of mean solar exoatmospheric irradiance for SPOT data, solar and topographic correction cannot be processed in this study. Therefore, only surface radiance is calculated in this study. However, this does not pose serious problem for analyzing temporal QOL changes as only the two SPOT images are used to derive the temporal change of QOL.

TM band 6 imagery can be converted to at satellite temperatures by Equation 3-4 (Markham and Barker, 1986).

$$T = \frac{K_2}{\ln(\frac{K_1}{L_\lambda} + 1)} \qquad (3-4)$$

where

T = Effective at satellite temperatures in Kelvin, K

K_2 = Calibration constant 2 in K

K_1 = Calibration constant 1 in mW•cm^{-2}•ster-1•µm^{-1}

L_λ = Spectral radiance at sensor aperture in mW•cm^{-2}•ster-1•µm^{-1} from equation 3-1

It is easier to convert SPOT image data into surface radiance using the Equation 3-5 (Price, 1987).

$$DN = \alpha_i^{-1}(m)\, L_\lambda \tag{3-5}$$

Assuming the calibration coefficients, β_i are 0, Equation 3-6 provide the value of α_i for Equation 3-5, calibration coefficients for SPOT (β=0) are provided in Table 3.6.

$$\alpha_i\,(\text{gain} = m) = \alpha_i(m_o)1.3^{(mo-m)} \tag{3-6}$$

where

L_λ = Spectral radiance at $Wm^{-2}sr^{-1}\mu m^{-1}$

α_i (m = gain) = electronic gain

DN = digital count in data tape

m_o = nominal gain

m = gain

Table 3.6 Calibration Coefficients for SPOT (β=0).

Spectral	HRV1 (α)	Nominal Gain (m_o)
XS1	1.08	5
XS2	1.14	6
XS3	1.06	5

Source: Price (1987)

However, surface reflectance cannot be obtained as some atmospheric parameters like down-scattered atmospheric radiance are not available in Hong Kong.

3.2.2 Image normalization

In order to reduce the atmospheric and radiometric effect on the two SPOT HRV images and make them comparable, relative image normalization is applied to the two scenes of SPOT images.

Apart from actual surface changes, factors such as sun angle, Earth-sun distance, detector calibration of the two HRV sensors, atmospheric conditions and sun target sensor geometry (phase angle) also affect pixel value (Eckhardt *et al.,* 1990). Image normalization suggested by Eckhardt *et al.* (1990) can help reduce these non-surface changes of the two SPOT scenes and predict the actual surface change condition.

The 1991 SPOT image is selected as the reference scene to the 1997 SPOT image as it has a lower off-nadir incidence angle. A total of 20 samples are obtained from non-vegetated land covers such as concrete surface buildings, beaches and airport runways which do not experience any landuse and land cover changes. Simple linear regression model in form of y = a + bx is applied to relate the digital values of reference scene (dependent variable) to the targeted scene (independent variable) as shown in Table 3.7.

Table 3.7 Regression model of Image Normalization for the SPOT images.

Channel	XS1	XS2	XS3
R^2*	0.589	0.709	0.696
A	146.976	127.655	120.754
B	0.525	0.6	0.592

*Significant at 0.005 level.

3.2.3 Geometric correction

Geometric correction is used to correct geometric distortion of an image with reference to a map and to register the image with coordinate for easier interpretation and change detection.

Both SPOT and TM images are geometrically rectified to the Hong Kong 1980 Grid using an image to map rectification method, a process by which the geometry of an image is made planimetric (Jensen, 1996). This process involves selecting same ground control points (GCP) on the image coordinates (rows and columns) and on the map coordinates. 42 GCPs are used to rectify 1991 SPOT image to 1991 1:20000 digital topographic map while 45 and 46 GCPs are used to rectify the 1996 TM and the 1997 SPOT image respectively. The image-to-map transformation use second order polynomial functions for geometric correction. The original 20 m by 20 m SPOT data were resampled to create images with 3000 columns by 2400 rows. Similarly, the original 30m by 30m Landsat data was resampled to 2000 Columns by 1600 rows. The root mean square errors for all images were less than 1 pixel (Table 3.8). Details of the GCP errors are listed in Appendix A.

Table 3.8 Root mean square errors of the geometrical corrections for the satellite images.

Satellite images	Ground Control Points collected	Root Mean Square Error		
		X	Y	Overall
1991 SPOT	46	0.39	0.48	0.62
1996 TM	45	0.49	0.28	0.56
1997 SPOT	42	0.40	0.47	0.62

3.3 Landuse and Land cover Classification

Four landuse and land cover types, namely water area, urban land, vegetation cover and vacant development land are extracted using 'linear unmixing' classification technique.

Water area includes sea, reservoirs and fish ponds. Urban land indicates the built-up land predominantly covered by buildings. Vegetation cover includes area covered with grass, shrubs and woodland. Vacant development land indicates areas without vegetation cover and areas with construction in progress.

The traditional approach to landuse and land cover mapping from remotely sensed data is through classification of each pixel to one land cover type. However, in the real world situation, a pixel may contain more than one landuse and land cover type. Classical classification methods are not appropriate when quantitative landuse and land cover information is required at sub-pixel level, especially in mapping urban landuse and land cover which a large number of pixels containing spectral contributions of more than one land cover (Gong *et al.*, 1991). Linear unmixing acts as an alternative approach for landuse and land cover classification that is capable to extract the proportion of specified landuse and land cover type for each pixel. Unlike laboratory spectral reflectance, which are usually measured from pure materials, a large proportion of remotely sensed data are spectrally mixed. In spectral mixing analysis, it is assumed that signatures of a subset number of surface elements can reproduce the observed spectra when mixed together in various proportions. This subset refers to endmembers, components or factors; they in fact may be mixtures themselves (Gong *et al.*, 1991). Fractions of each endmember can be obtained by the UNMIX algorithm using the software PCI Geomatics V7.0.

Linear unmixing can be described as a linear vector-matrix equation (Equation 3-7) under the assumption that an exhaustive set of endmembers has been defined (Equation 3-8) and each fraction must be positive (Schowengerdt, 1997).

$$DN_{ij} = Ef_{ij} + \varepsilon_{ij} \tag{3-7}$$

where

DN_{ij} = the K-dimensional spectral vector at pixel ij.

f_{ij} = L X 1 vector of L endmember fractions for the pixel at row i and column j

E = K X L endmember signature matrix, with each column containing one of the endmember spectral vector

ε_{ij} = residual error in the fitting of a given pixel's spectral vector by the sum of L endmember spectra and unknown noise

The summation of endmember fractions should equal to 1, so that

$$\sum_{l=1}^{L} f_1 = 1 \tag{3-8}$$

where

f_1 = set of endmembers where $f_1 \geq 0$

Number of endmembers should not exceed number of bands for the linear unmixing process. For SPOT images, there are only three bands and four landuse and land cover types to be generated. In order to avoid the errors, an additional NDVI band is also added as an input.

3.4 Spectral Data Extraction and Transformation

Spectral data extracted from satellite image are raster based, using pixel as the basic unit of study. However, in order to integrate with the vector based socioeconomic data, it is needed to convert the satellite image to vector polygons at TPU level. Mean and standard deviation of raw satellite data of each band after atmospheric and radiometric correction are extracted at TPU level. Moreover, mean and standard deviation of surface temperature and tasseled cap components at TPU level are extracted from TM images only. Mean and standard deviation of RVI, NDVI and SAVI are extracted from all the three satellite imageries.

Tasseled cap components, soil brightness, greenness and wetness are extracted from the TM image. Soil brightness refers to non-vegetated area, greenness refers to vegetation and wetness shows the degree of wetness in the study area using the Equation 3-9 (Schowengerdt, 1997)

$$TC = W_{TC} \bullet DN \tag{3-9}$$

where

TC = Tasseled cap Component

W_{TC} = Landsat coefficients as shown in Table 3.9.

DN = Digital Number of the TM image

Surface temperature affects the comfort of people and indicates the urban heat island effect which in turn affects quality of life. Surface temperature from TM image is extracted using Band 6 of TM data which records thermal infrared radiance at 10.3μm – 12.5μm. Surface temperature in Kelvin can be extracted using Equation

3-10 suggested by Malaret *et al.* (1985)

Table 3.9 Tasseled cap coefficients for the Landsat-5 TM.

	TM1	TM2	TM3	TM4	TM5	TM7	Additive term
Soil brightness	+0.2909	+0.2493	+0.4806	+0.5568	+0.4438	+0.1706	+10.3695
Greenness	-0.2728	-0.2174	-0.5508	+0.7221	+0.0733	-0.1648	-0.7310
Wetness	+0.1446	+0.1761	+0.3322	+0.3396	-0.6210	-0.4186	+3.3828

Source: Crist, Laurin and Cicone (1986) cited in Schowengerdt (1997)

$$T(K) = 209.831 + 0.834DN - 0.00133DN^2 \qquad (3\text{-}10)$$

where

T(K) = Surface temperature in Kelvin

DN = Digital numbers between 0 and 255

Three vegetation indices are extracted for analysis from all the three satellite images. Normalized Difference Vegetation Index (NDVI), Ratio Vegetation Index (RVI) and Soil Adjusted Vegetation Index (SAVI) are extracted from the TM and two SPOT images. NDVI is a commonly used vegetation indices for measuring vegetation vigor (Jensen, 1996). SAVI is applied in arid or semi-arid areas (Schowengerdt, 1997) which minimizes the soil brightness value (Qi *et al.*, 1993). It is applied for analysis in this study as the vegetation cover is lower in urban area and high in rural areas especially in country parks in Hong Kong. The L value indicates the vegetation cover with a value of 1 for high vegetation cover, Qi *et al.* (1993) suggested that a L value of 0.5 can significantly reduce soil brightness effects in low to highly vegetated canopies. Thus, L value of 0.5 is applied to Equation 3-13. Three Vegetation Indices are selected to compare the difference of the result using different vegetation indices.

NDVI, RVI and SAVI can be calculated using the Equations 3-11, 3-12 and 3-13.

$$NDVI = \frac{R_{NIR} - R_{RED}}{R_{NIR} + R_{RED}} \qquad (3-11)$$

$$RVI = \frac{R_{NIR}}{R_{RED}} \qquad (3-12)$$

$$SAVI = \left(\frac{R_{NIR} - R_{RED}}{R_{NIR} + R_{RED} + L} \right)(1 + L) \qquad (3-13)$$

where

R_{NIR} = Surface reflectance/ surface radiance of near-infrared band

R_{RED} = Surface reflectance/ surface radiance of visible red band

L = constant ranging from 0 to 1

3.5 Integration of Spectral and Census Data for Quality of Life Modeling

Two methods are used to integrate biophysical data and socioeconomic data for quality of life assessment. The first one is using stepwise multiple linear regression method to construct the relationship between socioeconomic and biophysical variables. The second one uses Principal Component Analysis for some selected variables to establish integrated quality of life indicators.

Given that the differences in the band width, resolution and sensor systems between Landsat TM and SPOT, data extracted from SPOT and Landsat TM images were not entirely comparable. Data extracted from these two images were used to integrate with socioeconomic data separately and hence to study the spatial pattern separately. In other words, the two satellite image types were included in the study for finding out if TM and SPOT images can be used in the integration model, but not for comparing their digital values.

3.5.1 Inter-relationship between biophysical data and socioeconomic data

In the operations of stepwise multiple regression modeling, there are two methods to derive the relationship: (1) the spectral variables are used as the dependent variable and census data as the independent variables and (2) census data are used as the dependent variable and spectral variables as the independent variables. The former shows how socioeconomic activities shape the physical environment whilst the latter shows if environmental factors have a strong effect on socioeconomic development.

3.5.2 Integrated quality of life modeling

Lo (1997) has proposed a method to integrate satellite image data with census data in Athens-Clarke County in Georgia, USA using population density, per capita income, median home value, percentage of college graduates, percentage of urban use, NDVI and surface temperature to derive an objective integrative indicator of life quality. The author adopted a similar approach. Variables of income, percentage of tertiary education, percentage of home ownership, population density, NDVI, percentage of urban landuse and surface temperature (for Landsat TM data only) are used to derive an integrative indicator with Principal Component Analysis. It is believed that such modification can fit the local characteristics of Hong Kong.

Quality of Life indicators extracted by Principal Component Analysis are plotted into maps using Arcview version 3.2 in order to assist visual interpretation.

3.6 Summary

Two types of data are utilized in this project. They are biophysical and socioeconomic data. Biophysical variables are extracted from the satellite images while socioeconomic variables are extracted from census reports.

Biophysical variables are extracted from three satellite images, namely 1991 SPOT, 1997 SPOT and 1996 TM to represent the biophysical environmental conditions in years 1991, 1997 and 1996 respectively. Radiometric and geometric corrections are applied to the satellite images so as to minimize the errors. Biophysical data like raw spectral data, vegetation indices, landuse and land cover, tasseled cap components and surface temperature are extracted from the satellite images at TPU level.

Socioeconomic data like population density, median household income, sex ratio, labour participation rate, percentage of home ownership, married population, education level, household size, age group and working sector are extracted from the 1991 census report and 1996 by-census report for further analysis at the TPU level.

Principal component analysis is used to generate uncorrelated components of biophysical and socioeconomic data. Stepwise linear regression modeling is used to examine the inter-relationships between socioeconomic and biophysical variables. Moreover, several variables are selected from biophysical and socioeconomic variables and integrated using principal component analysis to derive QOL indicators in Hong Kong.

CHAPTER FOUR DATA DESCRIPTION

This study included two types of data. They were socioeconomic data and biophysical data. Socioeconomic data were extracted from census report whilst biophysical data (also termed as "spectral data" in this study) were extracted from satellite imageries. All data were generated using Tertiary Planning Unit (TPU) as the basic unit for analysis. The objective of this chapter was to describe the nature of these data and explained their pattern of spatio-temporal variation in Hong Kong.

4.1 Socioeconomic Data

There were 24 socioeconomic data extracted from the 1991 census and the 1996 by-census reports respectively. These variables can be classified into ten groups according to their nature (Table 3.2). Moreover, principal components analysis (PCA) was used to extract factors from the 1991 Census and 1996 By-census data respectively so as to group these variables into a smaller number of factors for analysis.

Principal components analysis attempted to identify underlying variables or factors that explained the pattern of correlations within a set of observed variables. It was often used in data reduction to identify a small number of factors that explained most of the variance observed in a much larger number of manifest variables (SPSS, 1999) so that interpretation can be easier.

Six factors were extracted from 24 selected socioeconomic variables for the 1991 census data. In a descending order of the percentage of total variance explained (Table 4.1), six principal components extracted from the 1991 census data can be interpreted as

(1) Purchasing Power ($SPCA1_{91}$),

(2) Working Force ($SPCA2_{91}$),

(3) Large Household Size ($SPCA3_{91}$),

(4) Working Age Group ($SPCA4_{91}$),

(5) Degree of Crowdedness ($SPCA5_{91}$), and

(6) Home Ownership ($SPCA6_{91}$).

They explained 78.57% of the total variance.

Similarly, seven factors were extracted from 24 selected socioeconomic variables for the 1996 census. These seven principal components explained 77.54% of the total variance (Table 4.2). They can be interpreted as

(1) Purchasing Power ($SPCA1_{96}$),

(2) Working Force ($SPCA2_{96}$),

(3) Large Household Size ($SPCA3_{96}$),

(4) Medium Size Family ($SPCA4_{96}$),

(5) Working Age Group ($SPCA5_{96}$),

(6) Degree of Crowdedness ($SPCA6_{96}$), and

(7) Home Ownership ($SPCA7_{96}$).

It can be shown that except $SPCA4_{96}$, all components of the two years were showing similar loadings on the corresponding variables with thus similar meaning. They were sorted in a similar order as well.

Table 4.1 Principal Components of 24 socioeconomic variables extracted from 1991 census (Varimax rotation converged in 9 iterations)

	Component						Communal-ities
	1	2	3	4	5	6	
WORK3	**0.881**	-0.156	-0.105	0.163	0.177	0.048	0.872
PROF_LAB	**0.866**	0.322	-0.103	0.033	0.036	0.131	0.884
INCOME	**0.834**	0.299	0.092	0.011	-0.161	-0.161	0.846
TER	**0.815**	0.346	-0.138	0.073	-0.188	-0.020	0.845
WORK2	**-0.810**	0.267	0.180	-0.033	0.054	-0.165	0.791
ELEM	**-0.669**	-0.579	-0.073	-0.153	0.005	0.021	0.813
A40-54	**0.648**	0.401	-0.190	-0.153	0.116	-0.434	0.841
BOTH_LAB	0.141	**0.923**	0.071	-0.098	0.029	-0.079	0.893
M_LABOUR	0.050	**0.905**	0.188	-0.078	-0.004	-0.150	0.886
MARRY	0.142	**0.694**	-0.094	0.182	0.100	0.066	0.557
F_LABOUR	0.429	**0.664**	0.029	-0.108	0.073	0.129	0.660
SEX RATIO	0.064	**-0.504**	-0.165	0.427	0.100	-0.408	0.644
HH1	-0.005	0.027	**-0.911**	-0.083	-0.141	-0.099	0.867
HH5	-0.023	0.113	**0.904**	-0.125	0.046	-0.082	0.855
HH4	-0.106	0.195	**0.815**	0.237	0.306	-0.032	0.865
HH2	0.360	0.129	**-0.624**	0.176	0.063	0.494	0.815
A0-14	-0.295	0.412	**0.570**	0.210	-0.367	0.044	0.763
HH6	-0.262	-0.202	**0.501**	-0.448	-0.374	0.120	0.716
A55+	-0.225	-0.252	-0.237	**-0.830**	0.137	0.077	0.885
A15-39	-0.030	-0.417	-0.107	**0.720**	0.101	0.216	0.762
POP_DEN	-0.032	0.079	0.003	-0.244	**0.806**	-0.116	0.730
SEC	-0.106	0.169	0.201	0.244	**0.654**	0.259	0.634
HH3	0.014	-0.250	0.341	0.425	**0.601**	-0.132	0.738
OWNER	0.035	-0.047	-0.049	-0.013	-0.007	**0.831**	0.696
Eigenvalues	5.003	4.368	3.705	2.187	1.997	1.597	
Variance %	20.848	18.201	15.438	9.110	8.323	6.653	

Table 4.2 Principal Components extracted from 24 socioeconomic variables extracted from 1996 by-census (Varimax rotation converged in 12 iterations)

	Component							Commu-nalities
	1	2	3	4	5	6	7	
WORK3	**0.922**	-0.081	-0.111	0.046	0.048	0.160	-0.047	0.902
WORK2	**-0.913**	0.136	0.091	0.033	0.063	-0.033	-0.025	0.867
TER	**0.784**	0.414	-0.082	-0.078	0.052	0.047	0.192	0.841
INCOME	**0.716**	-0.047	-0.342	0.192	-0.134	-0.326	-0.120	0.814
SEC	**-0.703**	-0.047	-0.342	0.102	-0.143	-0.180	0.019	0.677
F_LABOUR	**0.663**	0.491	0.050	-0.003	0.244	-0.079	-0.068	0.753
A40-54	**0.548**	0.480	-0.234	0.235	-0.172	0.049	-0.145	0.693
BOTH_LAB	0.247	**0.890**	0.253	-0.071	0.107	0.051	-0.020	0.936
MARRY	-0.042	**0.883**	-0.130	0.118	-0.119	0.015	0.209	0.870
M_LABOUR	0.053	**0.858**	0.364	0.021	0.046	0.095	0.000	0.882
ELEM	-0.461	**-0.524**	0.420	0.025	0.053	0.096	-0.027	0.753
HH2	0.095	-0.035	**-0.772**	-0.136	0.136	0.010	0.214	0.689
A0-14	-0.094	0.088	**0.696**	0.286	0.244	-0.143	0.208	0.706
SEX_RATIO	-0.107	-0.349	**-0.626**	0.216	0.308	-0.241	-0.213	0.770
HH5	0.085	0.147	**0.620**	0.432	-0.126	-0.311	-0.156	0.736
HH6	0.015	-0.198	**0.516**	0.059	-0.460	-0.510	0.074	0.786
HH1	-0.042	-0.004	-0.323	**-0.884**	0.068	0.091	0.024	0.901
HH3	0.064	-0.001	-0.108	**0.774**	0.022	0.314	-0.018	0.714
HH4	-0.127	0.020	0.450	**0.668**	0.180	0.227	-0.159	0.781
A55+	-0.239	-0.216	-0.156	-0.254	**-0.782**	0.185	-0.050	0.841
A15-39	-0.094	-0.229	-0.270	-0.168	**0.782**	-0.114	-0.016	0.787
POP_DEN	-0.024	-0.003	-0.019	0.167	-0.213	**0.744**	-0.160	0.654
PROF_LAB	0.315	0.097	-0.021	0.133	-0.084	**0.473**	0.135	0.375
OWNER	-0.029	0.128	-0.045	-0.098	0.007	-0.053	**0.920**	0.878
Eigenvalue	5.861	4.009	2.512	1.966	1.936	1.276	1.048	
Variance %	24.422	16.704	10.468	8.191	8.065	5.317	4.368	

$SPCA1_{91}$, purchasing power, was positively and heavily loaded on percentage of tertiary working sector (WORK3), percentage of professional labour (PROF_LAB), average median household income (INCOME), percentage of tertiary educated population (TER) and percentage of population aged 40-54 (A40-54); but negatively loaded on percentage of secondary sector workers (WORK2) and percentage of population with elementary education level (ELEM). TPUs with a larger proportion of middle aged population engaged in tertiary sectors or professional occupation with university degrees and high income tended to fetch a higher factor score. It was thus interpreted as purchasing power. It was obvious that $SPCA1_{96}$ is also related to purchasing power. It had similar loadings on the dominant variables to $SPCA1_{91}$.

$SPCA2_{91}$ was interpreted as working force. The variables showing positive loading included both labour participation rate (BOTH_LAB), male labour participation rate (M_LABOUR), percentage of married population (MARRY) and female labour participation rate (F_LABOUR). Meanwhile, a negative relationship with sex ratio (SEX_RATIO) was noted. TPUs with a larger proportion of married population engaged into the working force yielded a higher factor score. It also showed the pattern that this population group had more female than male. A similar situation was found for $SPCA2_{96}$, thus it was also interpreted as working force.

$SPCA3_{91}$ and $SPCA3_{96}$ were identified as large household size. $SPCA3_{91}$ was positively and heavily loaded on percentage of household size 4 (HH4), household size 5 (HH5), household size 6 (HH6) and percentage of population aged 0-14 (A0_14) but negatively loaded on percentage of household size 1 (HH1) and household size 2 (HH2). The loadings were associated with the household size.

TPUs with a higher proportion of household size with four to over six persons and having children yielded a higher factor score. The $SPCA3_{96}$ showed similar loadings which had strong positive loading on HH5, HH6 and negatively on HH2.

$SPCA4_{91}$ and $SPCA5_{96}$ were interpreted as working age group. They were positively and heavily loaded on percentage of population aged 15-39 (A15-39) and negatively loaded on percentage of population aged 55 and above (A55+). TPUs with a higher proportion of young population and less old population tended to produce a higher factor score.

$SPCA5_{91}$ was degree of crowdedness. It was heavily and positively loaded on population density (POP_DEN), secondary educated people (SEC) and percentage of household size 3 (HH3). From the census data, it was found that high values of POP_DEN, SEC and HH3 were found in districts like Mongkok, Wong Tai Sin, Kwun Tong, North Point and Tsuen Wan. Since population density had the highest loading in this component, $SPCA5_{91}$ was thus interpreted as degree of crowdedness. $SPCA6_{96}$ was also interpreted as degree of crowdedness as it had strong and positive loadings on population density.

$SPCA6_{91}$ and $SPCA7_{96}$ were interpreted as home ownership as it had a positive and dominantly loading on percentage of home ownership (OWNER). TPUs with higher factor scores were areas with higher proportion of population who own their houses.

$SPCA4_{96}$ was interpreted as medium size family. It was positively and strongly loaded on household size of 3 persons (HH3) and household size of 4 persons (HH4).

It was negatively loaded on percentage of population with 1 person (HH1). It showed that TPUs with higher proportion of family size with three to four persons yielded a higher factor score.

Changes in socioeconomic data were acquired by finding the difference between the 1991census data and the 1996 by-census data. The changes were then used to derive the principal components to reveal the changes in socioeconomic conditions. As shown in Table 4.3, eight principal components were extracted and explained 71.07% of the total variance. A positive loading represented an increase in the value of the data, a negative loading represented a decrease in the value of the data.

The first component ($SPCA1_{9196}$) was interpreted as increase in labour participation. It was positively and heavily loaded on both labour participation rate (Δ BOTH_LAB), and male labour participation rate (Δ M_LABOUR). It was negatively loaded on percentage of population aged 55 and above (Δ A55+). There was less old population engaged in the working force in their old age. TPUs having a higher score showed that there was an increase in the proportion of population participated in the working force and fewer old people

The second component ($SPCA2_{9196}$) was interpreted as less educated population. It was positively and heavily loaded on percentage of population with elementary education (Δ ELEM) and percentage of household size of 6 (Δ HH6). However, it was negatively loaded on percentage of professional labour (Δ PROF_LAB), percentage of household size 2 (Δ HH2) and percentage of population with secondary education (Δ SEC). It showed that the increase in household size with people of low educational attainment may be resulted from the influx of immigrants

Table 4.3 Principal Components extracted from changes in 24 socioeconomic variables extracted from 1996 by-census and 1991 census (Varimax rotation converged in 8 iterations)

	Components								Comm-unality
	1	2	3	4	5	6	7	8	
BOTH_LAB	**0.840**	0.076	-0.122	0.244	-0.120	0.234	0.101	0.091	0.873
M_LABOUR	**0.815**	-0.121	-0.122	0.227	-0.120	0.064	-0.100	0.040	0.775
A55+	**-0.752**	0.129	-0.213	-0.099	-0.233	0.064	0.190	0.044	0.734
ELEM	-0.284	**0.745**	-0.059	-0.031	0.135	-0.162	0.125	0.094	0.709
PROF_LAB	-0.114	**-0.734**	0.344	0.128	-0.038	0.047	-0.065	0.090	0.702
HH2	-0.035	**-0.534**	0.074	0.080	0.157	0.512	0.342	-0.078	0.708
HH6	-0.409	**0.510**	-0.109	0.121	0.047	0.166	-0.093	0.488	0.73
SEC	0.010	**-0.479**	-0.454	-0.249	0.315	-0.110	0.146	0.306	0.723
WORK2	0.077	0.050	**-0.891**	0.087	-0.135	0.044	0.006	0.037	0.832
WORK3	0.062	-0.205	**0.871**	-0.133	0.173	-0.100	0.004	-0.030	0.863
A40-54	0.245	-0.036	-0.054	**0.802**	0.056	-0.044	0.095	-0.041	0.724
INCOME	0.214	0.393	0.131	**0.578**	0.129	0.320	0.002	0.183	0.704
A15-39	0.450	-0.062	0.221	**-0.578**	-0.006	0.015	0.424	-0.051	0.772
TER	0.161	-0.308	0.493	**0.526**	-0.184	0.064	0.040	0.076	0.686
OWNER	-0.189	0.071	0.143	**-0.493**	0.328	0.056	0.160	0.097	0.45
MARRY	0.209	-0.244	-0.137	**0.467**	0.293	-0.194	0.388	0.074	0.62
HH4	0.025	-0.042	0.057	0.046	**0.797**	-0.050	-0.174	-0.082	0.682
HH1	0.075	-0.122	-0.142	0.036	**-0.770**	-0.332	0.004	-0.025	0.746
SEX_RATIO	-0.023	0.198	0.171	0.080	-0.115	**-0.786**	0.078	0.041	0.714
F_LABOUR	0.468	0.216	0.097	0.038	0.040	**0.686**	0.128	0.101	0.775
HH3	0.053	0.153	0.112	-0.078	0.427	**-0.444**	0.442	0.028	0.62
A0_14	0.169	-0.052	0.059	-0.005	0.239	-0.075	**-0.846**	0.032	0.815
HH5	0.124	0.296	-0.031	-0.074	0.292	0.131	-0.250	**0.650**	0.696
POP_DEN	-0.029	0.131	0.017	-0.036	0.185	0.092	-0.099	**-0.574**	0.402
Eigenvalues	2.894	2.502	2.405	2.319	2.126	1.984	1.626	2.894	
Variance (%)	12.057	10.423	10.019	9.664	8.86	8.267	6.776	12.057	

from China between 1991 and 1996. TPUs with more population with decreased educational attainment and living in a large household tended to yield a higher factor score.

The third component ($SPCA3_{9196}$) was interpreted as economic restructuring from secondary sector industry to tertiary sector industry. This can be shown by a positive and heavy loading on percentage of tertiary sector workers (ΔWORK3) but a negative loading on percentage of secondary sector workers (ΔWORK2). It meant that in TPUs where a large proportion of population had changed their job from secondary sector to tertiary sector would have a higher factor score.

The fourth component ($SPCA4_{9196}$) was interpreted as increase in purchasing power. It was positively loaded on percentage of population aged 40-54 (ΔA40-54), average median household income (ΔINCOME), percentage of population with tertiary education level (ΔTER) and percentage of married population (ΔMARRY); but negatively loaded on percentage of population aged 15-39 (ΔA15-39) and percentage of home ownership (ΔOWNER). There was an increase in married and middle aged population who earn high income and have a university degree. The increase in this population group who had high income would in turn lead to an increase in purchasing power. Working age group who were aged 15 to 39 had just started their career path and did not have high income. As most owners had to spend a large part of their income for their mortgage loan, their purchasing power was not high. TPUs with increased proportion of married population who can earn high income and have a university degree resulted in a higher factor score.

The fifth ($SPCA5_{9196}$), sixth ($SPCA6_{9196}$) and seventh ($SPCA7_{9196}$) components were interpreted as increase in medium size family, increase in female labour participation and decrease in children population respectively. $SPCA5_{9196}$ was shown by the positively dominant loading of percentage of household size 4 (ΔHH4) but negative loading of percentage of household size 2 (ΔHH2). TPUs with an increase in medium size family had a higher factor score. $SPCA6_{9196}$ was positively and heavily loaded on female labour participation rate (ΔF_LABOUR) but negatively loaded on sex ratio (ΔSEX_RATIO) and percentage of household size 3 (ΔHH3). TPUs with an increase proportion of female from medium size family and engaged in working sectors yielded a higher positive score. $SPCA7_{9196}$ was negatively and heavily loaded on percentage of population aged 0-14 (ΔA0-14). TPUs with an increase in proportion of children resulted in a higher factor score.

The last component was not easy to be interpreted. It was positively and heavily loaded on percentage of household size 5 (ΔHH5) but negatively loaded on population density (ΔPOP_DEN). As population density was lowered, degree of crowdedness would be lowered. However, it was contradictory as TPUs with a decrease in degree of crowdedness had an increasing in family members which would raise the population density.

4.2 Spectral Data

4.2.1 Raw data

Landsat TM imagery has seven bands, namely, TM1, TM2, TM3, TM4, TM5, TM6 and TM7. TM1 (0.45μm to 0.52μm) is the blue band. It provides increased penetration of water bodies as well as providing data for analyzing landuse, soil and vegetation characteristics. TM2 (0.52μm to 0.60μm) is the green band. It spans the regions between the blue and red chlorophyll absorption bands which correspond to the high green reflectance of healthy vegetation. TM3 (0.63μm to 0.69μm) is the red band which is the red chlorophyll absorption band of healthy green vegetation. TM4 (0.76μm to 0.90μm) is the near-infrared band. It is especially responsive to the amount of vegetation biomass present in a scene. TM5 (1.55μm to 1.75μm) is a mid-infrared band that is sensitive to the turgidity or amount of water in plants. TM6 (10.4μm to 12.5 μm) is a thermal infrared band. It measures the amount of thermal infrared radiant flux emitted from surfaces and is useful for locating geo-thermal activity, thermal inertia mapping for geologic investigations, vegetation classification, vegetation stress analysis and soil moisture studies. TM7 (2.08μm to 2.35 μm) is a mid-infrared band which is important for the discrimination of geologic rock formations (Jensen, 2000).

SPOT imagery has three multispectral bands, namely XS1, XS2 and XS3. XS1 (0.5μm to 0.59 μm), the visible green band, is commonly applied to extract green reflectance of healthy vegetation as well as some water details in shallow areas. XS2 (0.61μm to 0.68 μm), the visible red band, is generally applied in extracting chlorophyll absorption of green vegetation for plant differentiation. XS3 (0.79μm to 0.89 μm), the near infrared band, is commonly applied in biomass studies, water body delineation and vegetation reflectance extraction.

4.2.2 Landuse and Land cover

Value of water area was high in Northwest New Territories where fish ponds and wetland were present. It was also high in TPUs consisting of islands, reservoirs, coastal area and river. Since the resolution of a pixel is 20 meters and 30 meters for SPOT and TM images respectively, parts of sea and rivers may be included in the pixel presenting land areas that yield a higher value. Diversity of water area did not show a meaningful pattern from the satellite images as all the data were extracted in land area.

Figures 4.1, 4.2 and 4.3 illustrated the percentage of urban areas extracted from 1991 SPOT, 1996 TM and 1997 SPOT respectively. Percentage of urban area was high in metropolitan area and new towns where population concentrated but low in rural area. Diversity of urban area was higher in Northwest New Territories and in metropolitan areas but lower in rural area especially in the country parks. It was because the mixed landuse in metropolitan area and Northwest New Territories leaded to a higher standard deviation compared to more uniform land cover of rural areas and country parks.

Figures 4.4, 4.5 and 4.6 illustrated the percentage of vegetated areas extracted from the 1991 SPOT, 1996 TM and 1997 SPOT respectively. Vegetated area was located at the rural area and country parks, and had low value in metropolitan area. The value was especially high in country parks due to plantation and conservation of country parks in Hong Kong. Diversity of vegetated area was lower in urban area and higher in rural area which illustrated the mixed woodland, grassland and other landuse like storage area and villages in rural area.

Vacant development land were found in reclamation land without buildings like Tseung Kwan O, Tai Po Industrial Area, Kai Tak Airport and the new airport.

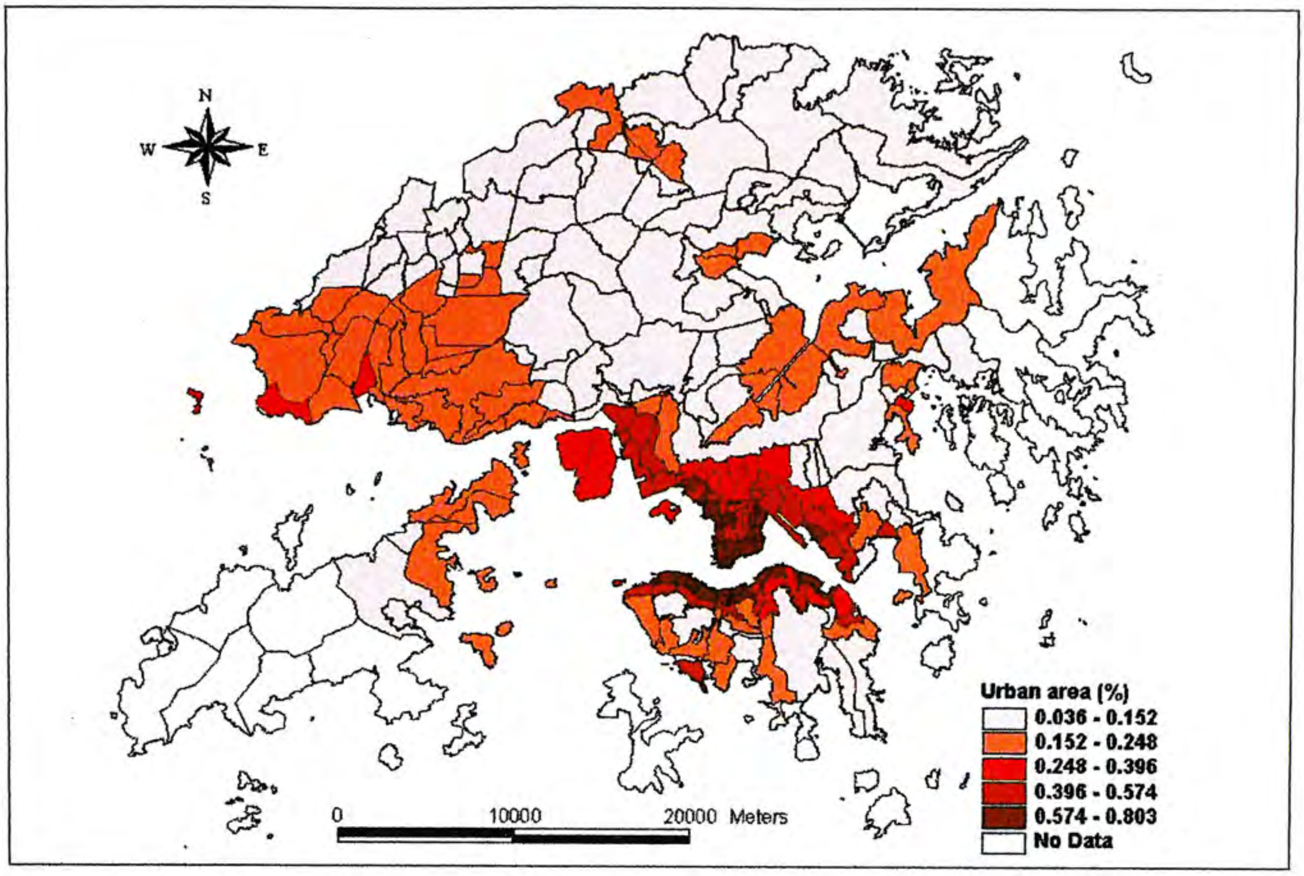


Figure 4.1 Urban Area extracted from 1991 SPOT

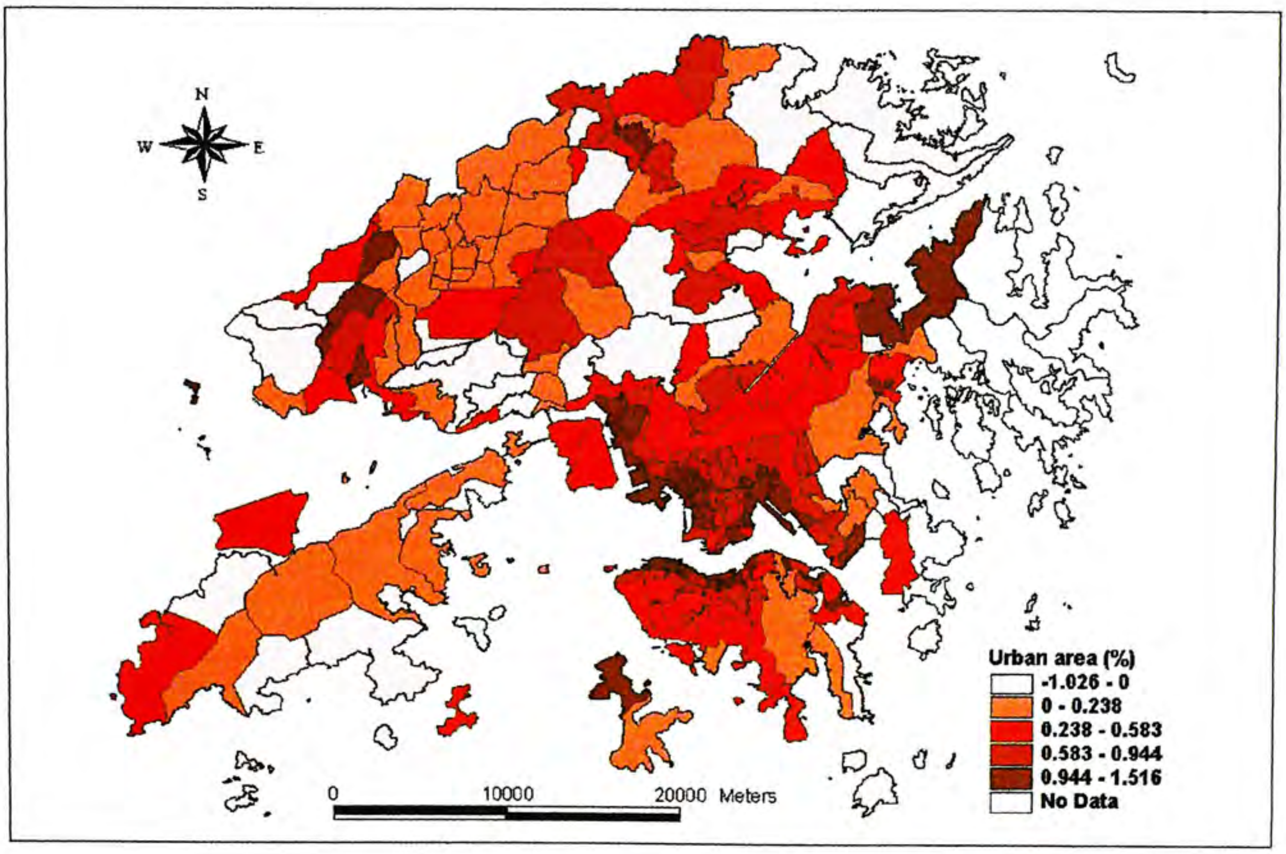


Figure 4.2 Urban Area extracted from 1996 TM

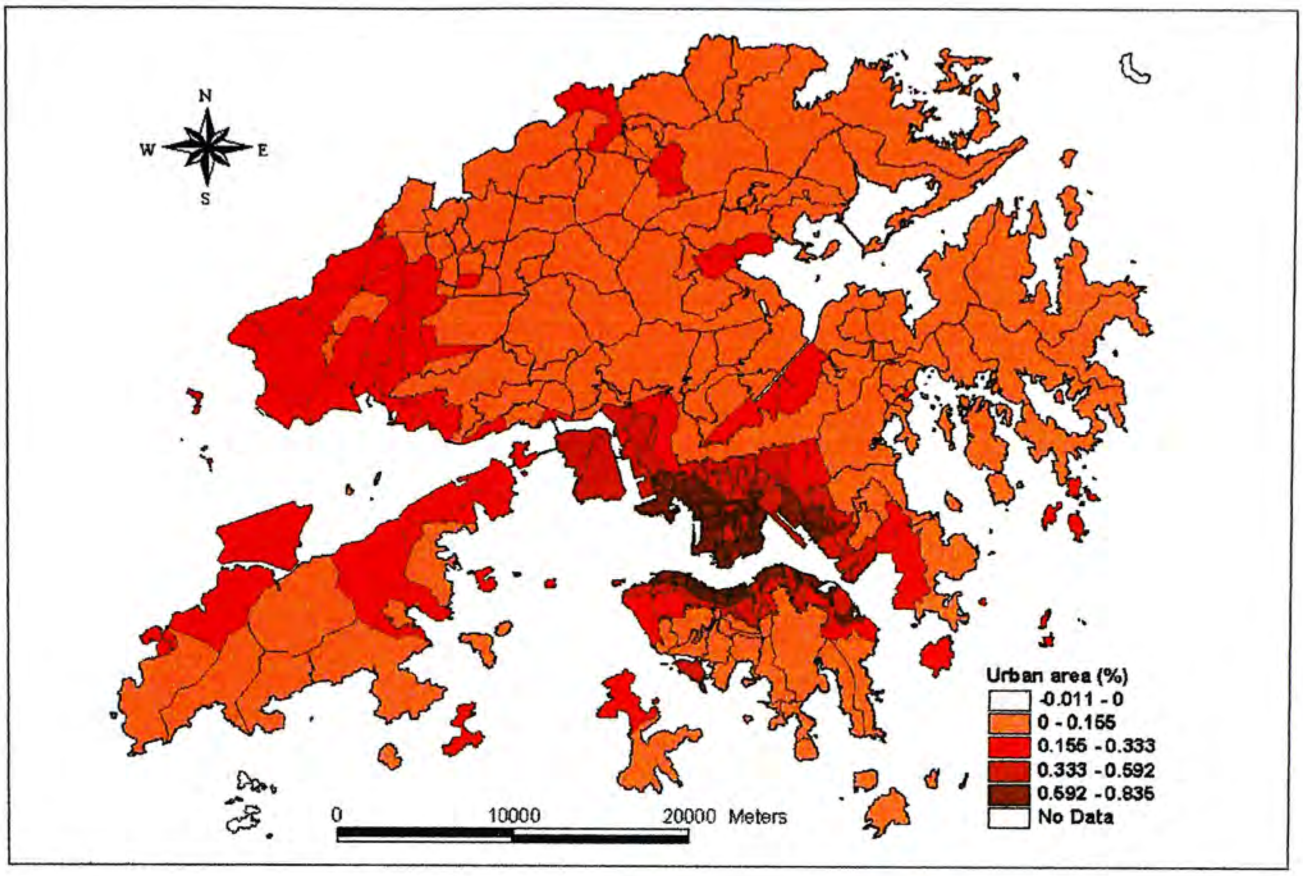


Figure 4.3 Urban Area extracted from 1997 SPOT

Diversity of vacant development land was the highest in Tseung Kwan O where there was mixed landuse and land cover of vacant development land, residential area and countryside.

4.2.3 Vegetation indices

Three types of vegetation indices showing vegetation vigor were selected in this study. They were the NDVI, RVI and SAVI. All three vegetation indices showed a similar pattern. Generally, the value of vegetation indices was higher in rural area and in country parks due to higher vegetation vigor in these areas. Within urban area, high vegetation vigor was found in new towns and area with low-density residential development like Kowloon Tong than in the old metropolitan area. Since one of the objectives of developing new towns was to improve life quality of the people who moved into the new towns, sufficient greening and open spaces were planned in the design of new towns. Low-density residential areas were occupied by the high income group who asked for a better living environment which was less crowded with more open spaces and greening provided. Thus new towns and low-density residential area had a higher value in vegetation indices.

Diversity of vegetation indices was relatively high in new town but low in metropolitan area and rural area. It was because the variation in landuse and land cover was high in new towns where mixture of open spaces, buildings and vegetation cover are common. Thus the variation was higher in new towns as compared to uniform buildings in metropolitan area.

4.2.4 Tasseled cap components

Soil brightness was higher in urban area than in rural area like Kai Tak Airport and newly reclaimed area but lowest in country parks where exposed bare soil was limited. Diversity of soil brightness was highest in coastal area and newly reclaimed land.

Greenness was highest in country parks and lowest in urban areas. Diversity of greenness was high in the International Airport, Tseung Kwan O and Ma On Shan where there was mixed landuse of open space, vegetation and urban landuse interface. The value was low in urban area where only buildings are found.

Wetness was high in coastal area and in Northwest New Territories where fishponds

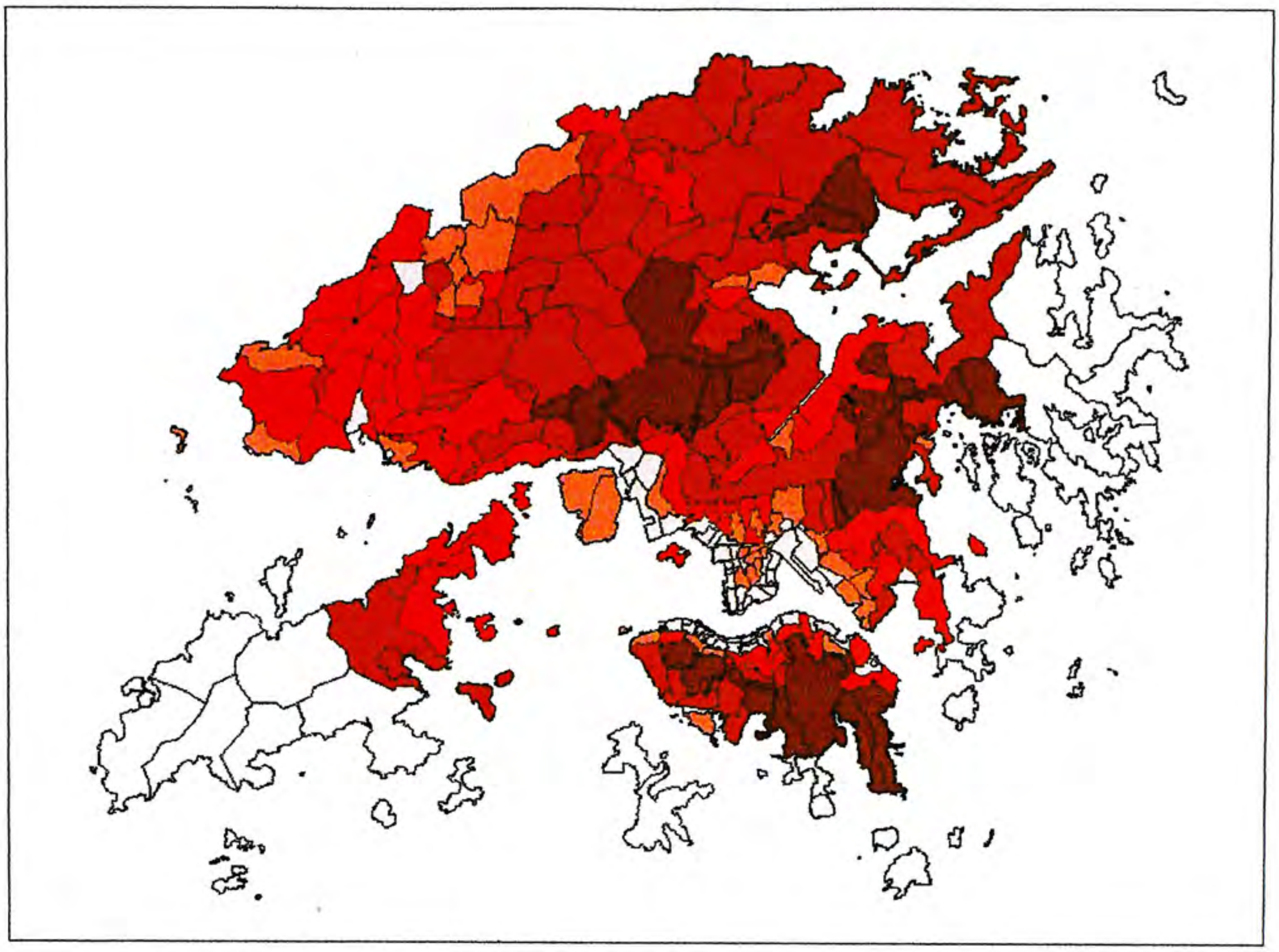


Figure 4.4. NDVI extracted from 1991 SPOT

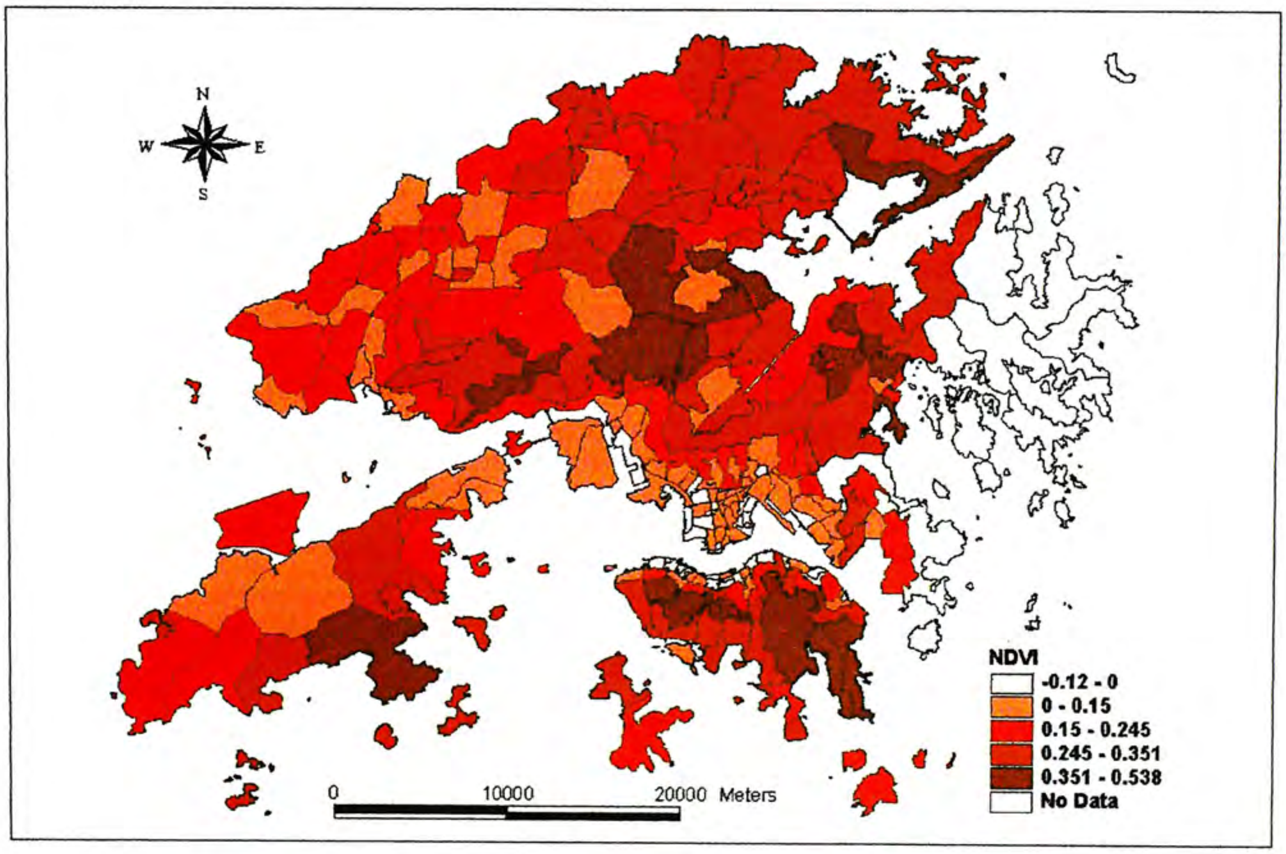


Figure 4.5 NDVI extracted from 1996 TM

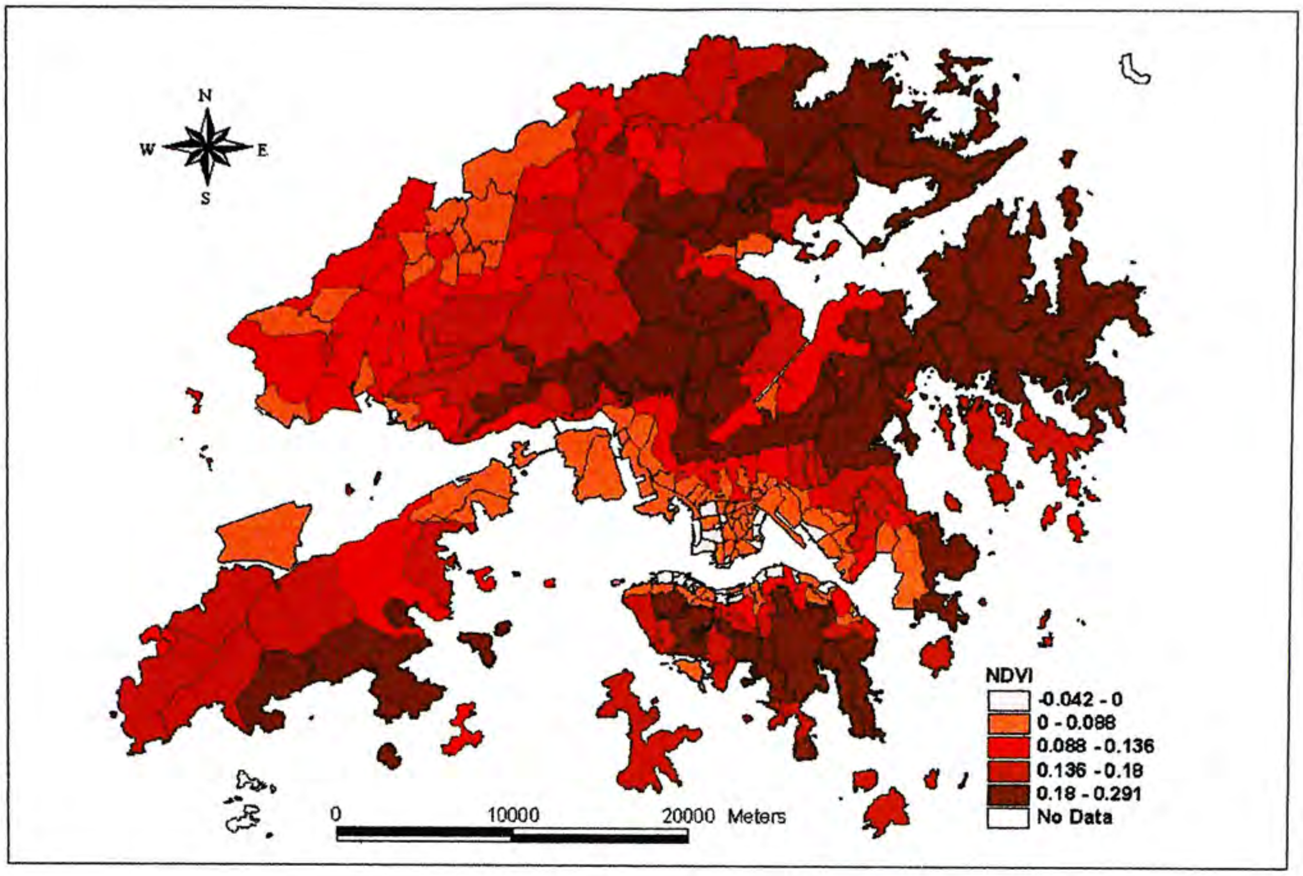


Figure 4.6 NDVI extracted from 1997 SPOT

were located. Diversity of wetness was highest in coastal area and lowest in urban area.

4.2.5 Surface temperature

Figure 4.7 showed the spatial temperature variation on 3rd March, 1996 which was extracted from the 1996 TM data. Surface temperature ranged from 15°C to 21°C as extracted from the TM image. It fell well within the temperature range, 15.7°C to 20.6°C, which was recorded by the Royal Hong Kong Observatory on 3rd March, 1996 (Royal Hong Kong Observatory, 1996). Surface Temperature was highest in Yuen Long (21°C) and lowest in coastal area and in eastern Hong Kong (15°C). On the date when the TM image was acquired, Kai Kung Leng, Tai To Yan, Tai Mo Shan and Pat Sin Leng acted as barriers protecting the Yuen Long Plain from

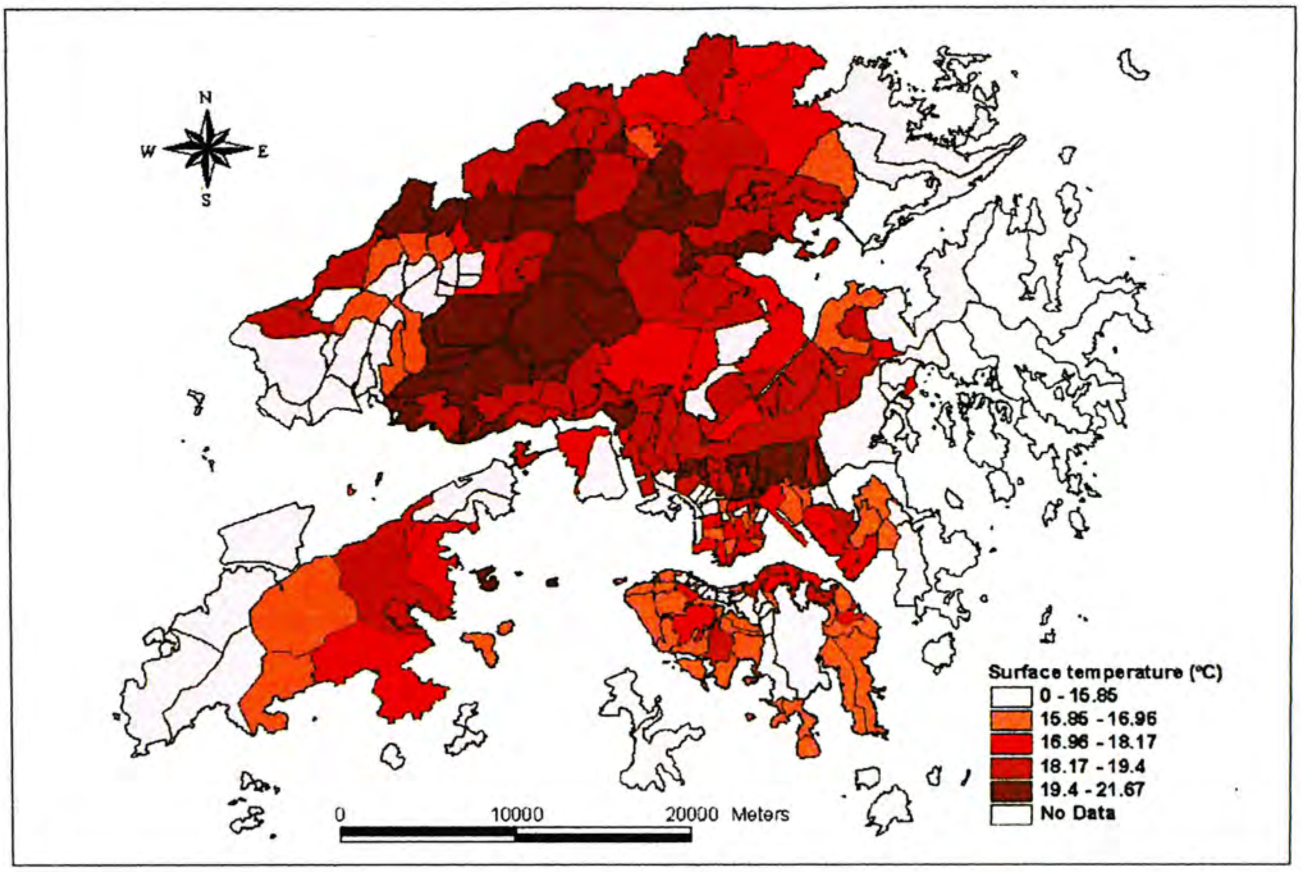


Figure 4.7 Surface temperature extracted from 1996 TM

east-northeast wind. A lower temperature in coastal area and eastern Hong Kong was due to the influence of water-cooling effect and the cold wind.

4.2.6 Principal components extracted from biophysical variables

Three principal components were extracted from the 1991 biophysical variables extracted from the 1991 SPOT data using Principal Component Analysis. They explained 86.73% of the total variance (Table 4.4). The first component ($BPAC1_{91}$) represented the vegetation vigor. The second component ($BPAC2_{91}$) represented the diversity of vegetation. The third component ($BPAC3_{91}$) represented soil brightness.

Table 4.4 Principal components of 1991 biophysical variables extracted from 1991 SPOT (Varimax rotation converged in 6 iterations)

	Components			Communality
	1	2	3	
XS3M	**0.931**	0.173	0.242	0.955
NDVIM	**0.922**	0.183	-0.320	0.985
SAVIM	**0.907**	0.179	-0.322	0.959
VEGM	**0.906**	0.173	-0.344	0.969
RVIM	**0.903**	0.196	-0.352	0.978
URBANM	**-0.890**	-0.165	0.000	0.819
WATERM	**-0.615**	0.007	0.117	0.393
NDVID	0.002	**0.969**	-0.029	0.941
SAVID	-0.008	**0.942**	-0.038	0.889
WATERD	0.243	**0.860**	0.274	0.873
URBAND	0.174	**0.845**	0.351	0.869
VEGD	0.427	**0.837**	0.082	0.889
RVID	0.533	**0.777**	-0.251	0.951
XS3D	0.193	**0.753**	0.370	0.741
BAREM	-0.160	-0.085	**0.931**	0.899
XS2M	-0.320	-0.062	**0.908**	0.931
XS1M	-0.406	-0.032	**0.857**	0.900
BARED	0.025	0.391	**0.825**	0.834
XS2D	-0.075	0.435	**0.798**	0.832
XS1D	-0.198	0.439	**0.713**	0.741
Eigenvalue	6.276	5.892	5.178	
Variance %	31.381	29.458	25.892	

Six principal components were extracted from biophysical variables of the 1996 TM. The six components explained 87.52% of the total variance (Table 4.5). The first component ($BPCA1_{96}$) represented soil brightness. The second component ($BPCA2_{96}$) was interpreted as vegetation vigor. The third component ($BPCA3_{96}$) was diversity of soil brightness. The fourth component ($BPCA4_{96}$) was interpreted as diversity of vegetation. The fifth component ($BPCA5_{96}$) was water area. The sixth component ($BPCA6_{96}$) was interpreted as surface temperature.

Five principal components were extracted from biophysical variables of 1997 SPOT data and explained 92.21% of the total variance (Table 4.6). The first component ($BPCA1_{97}$) was vegetation vigor. The second component ($BPCA2_{97}$) showed the soil brightness. The third component ($BPCA3_{97}$) was interpreted as diversity of vegetation. The fourth component ($BPCA4_{97}$) was water area. The fifth component ($BPCA5_{97}$) was interpreted as diversity of urban area.

$BPCA1_{91}$ and $BPCA1_{97}$ were vegetation vigor in which loadings were dominated by XS3M, NDVIM, SAVIM, VEGM and RVIM positively. XS3M, the near-infrared band, had a high reflectance on vegetation, NDVIM, SAVIM, VEGM and RVIM were vegetation indices showing the vegetation vigor. URBANM had a strong negative loading on these components. Vegetation vigor was low in urban area where buildings occupied. Thus, TPUs with high factor scores in these two principal components were interpreted as having high vegetation vigor.

Table 4.5. Principal components of biophysical variables extracted from 1996 TM (Varimax rotation converged in 7 iterations)

	Components						Communalit-ies
	1	2	3	4	5	6	
SOILM	**0.967**	0.074	0.111	-0.019	0.023	0.097	0.964
TM5M	**0.944**	0.216	0.162	-0.086	-0.066	-0.005	0.976
TM7M	**0.910**	-0.225	0.197	-0.152	-0.178	0.042	0.975
BAREM	**0.829**	-0.077	0.315	-0.169	0.248	-0.068	0.887
TM2M	**0.823**	-0.447	0.090	-0.018	0.129	0.172	0.932
TM3M	**0.814**	-0.475	0.173	-0.105	0.022	0.135	0.949
WETM	**-0.775**	-0.045	-0.253	0.241	0.307	0.132	0.836
TM1M	**0.762**	-0.466	-0.047	0.074	0.229	0.219	0.906
URBAND	**0.713**	-0.094	0.312	0.313	-0.097	-0.065	0.726
WATERD	**0.689**	-0.248	0.362	0.264	-0.063	-0.036	0.742
TM4M	**0.683**	0.663	-0.014	0.126	0.073	0.075	0.932
TM6M	**0.635**	-0.100	-0.347	0.237	0.354	0.295	0.802
WETD	**0.613**	0.092	0.585	0.153	0.136	-0.054	0.772
NDVIM	-0.147	**0.959**	-0.080	0.138	-0.025	-0.079	0.974
GREENM	-0.172	**0.952**	-0.123	0.163	0.023	-0.072	0.983
RVIM	-0.188	**0.941**	-0.099	0.139	0.001	-0.063	0.953
VEGM	-0.102	**0.885**	-0.157	0.240	0.280	-0.002	0.954
SAVIM	-0.092	**0.867**	-0.059	0.089	-0.026	0.060	0.775
RVID	-0.124	**0.737**	0.004	0.631	0.045	0.001	0.958
SOILD	0.258	-0.188	**0.924**	-0.032	0.071	-0.029	0.963
TM2D	0.150	-0.174	**0.905**	0.006	-0.087	0.020	0.880
TM1D	-0.130)	-0.026	**0.862**	0.007	-0.225	-0.054	0.815
TM3D	0.358	-0.189	**0.852**	0.043	0.026	0.057	0.896
TM4D	0.074	0.148	**0.827**	0.252	0.016	-0.083	0.783
TM5D	0.403	-0.088	**0.824**	0.018	0.184	-0.050	0.886
TM7D	0.547	-0.140	**0.753**	0.110	0.051	0.011	0.900
BARED	0.563	0.068	**0.649**	0.021	0.232	-0.071	0.803
TM6D	-0.334	0.232	**0.522**	-0.078	-0.271	-0.307	0.611
NDVID	-0.056	0.315	0.148	**0.849**	0.250	0.032	0.908
GREEND	0.057	0.647	0.062	**0.704**	0.012	-0.001	0.922
VEGD	0.211	0.621	0.186	**0.624**	-0.233	-0.104	0.918
SAVID	-0.071	0.416	0.077	**0.612**	0.016	-0.165	0.585
WATERM	-0.018	0.040	0.026	0.075	**0.948**	-0.014	0.907
URBANM	-0.085	-0.657	-0.051	-0.063	**-0.672**	0.114	0.910
TEMPERD	-0.017	0.112	0.020	0.036	0.041	**-0.948**	0.914
TEMPERM	0.100	0.021	-0.106	-0.078	-0.008	**0.937**	0.906
Eigenvalue	9.421	7.803	6.880	3.006	2.202	2.193	
Variance %	26.169	21.675	19.112	8.349	6.118	6.092	

Table 4.6. Principal components of biophysical variables extracted from 1997 SPOT (Varimax rotation converged in 8 iterations)

	Components					Communalities
	1	2	3	4	5	
NDVIM	**0.899**	-0.313	0.246	-0.146	-0.004	0.985
XS3M	**0.899**	0.316	0.127	-0.195	0.029	0.963
URBANM	**-0.898**	0.099	-0.210	-0.329	-0.126	0.989
RVIM	**0.889**	-0.326	0.240	-0.186	-0.012	0.869
SAVIM	**0.883**	-0.347	0.244	-0.126	-0.011	0.976
VEGM	**0.868**	-0.365	0.260	-0.143	-0.103	0.919
BARED	-0.032	**0.914**	0.211	0.026	-0.028	0.918
XS2D	-0.146	**0.912**	0.200	-0.004	-0.023	0.893
XS2M	-0.338	**0.868**	-0.243	0.026	0.035	0.929
XS1D	-0.275	**0.848**	0.194	-0.034	-0.003	0.834
XS1M	-0.397	**0.846**	-0.199	0.049	0.018	0.916
BAREM	0.163	**0.745**	-0.226	0.411	0.260	0.985
XS3D	-0.002	**0.623**	0.576	-0.183	-0.068	0.758
SAVID	0.097	0.027	**0.941**	0.134	0.144	0.935
NDVID	0.273	-0.003	**0.932**	0.062	0.148	0.924
RVID	0.523	-0.114	**0.814**	-0.056	0.123	0.883
VEGD	0.499	0.004	**0.806**	-0.002	0.160	0.841
WATERD	0.204	0.436	**0.721**	-0.059	-0.294	0.969
WATERM	-0.281	0.054	0.111	**0.903**	-0.094	0.989
URBAND	0.012	0.053	0.230	-0.069	**0.926**	0.968
Eigenvalue	5.871	5.576	4.563	1.295	1.139	
Variance %	29.353	27.879	22.813	6.474	5.695	

$BPCA2_{91}$ and $BPCA3_{97}$ were interpreted as diversity of vegetation. NDVID, SAVID, VEGD, RVID, XS3D and WATERD were positively loaded on these two components. As mentioned above, vegetation indices and near-infrared band showed the vegetation vigor. As water areas like reservoirs were located at country parks where vegetation cover was high, a high loading on WATERD was resulted due to the mixing with surrounding vegetation cover. TPUs with high factor scores were areas showing higher diversity of vegetation.

$BPCA3_{91}$ and $BPCA2_{97}$ were interpreted as soil brightness since they have positive and dominant loadings on BAREM, XS2M, XS1M, BARED, XS1D and XS2D. XS1M, XS1D, XS2M and XS2D showed the mean and diversity of green and red visible band respectively, while BAREM and BARED showed the mean and diversity of vacant development land respectively. For TPUs with high factor scores showed higher soil brightness especially in vacant development land.

$BPCA4_{97}$ was water area. The component was positively loaded with WATERM only. TPUs with higher proportion of water area resulted in a higher factor score in $BPCA4_{97}$.

$BPCA5_{97}$ was diversity of urban areas as its dominant loading was positively related to URBAND. TPUs with higher factor scores experienced a high diversity of urban area.

For 1996 data set, $BPCA1_{96}$ was soil brightness. The positive dominant components were SOILM, TM5M, TM7M, BAREM, TM2M, TM3M, WETM, TM1M, URBAND, WATERD, TM4M, TM6M and WETD. TPUs with high factor scores in this component showed a higher soil brightness value.

With reference to the positive and dominant loadings on the vegetation indices like NDVIM, GREENM, RVIM, VEGM, SAVIM and RVID, $BPCA2_{96}$ were interpreted as vegetation vigor. TPUs with high factor scores in this component had high vegetation vigor.

$BPCA3_{96}$ were diversity of soil brightness due to the positive loadings on SOILD, TM2D, TM1D, TM3D, TM4D, TM5D, TM7D, BARED and TM7D. Most of the loadings were on the raw spectral band, soil brightness and vacant development land. TPUs with high factor scores in $BPCA3_{96}$ were areas with high diversity of soil brightness.

$BPCA4_{96}$ represented diversity of vegetation vigor and it was positively loaded on NDVID, GREEND, VEGD and SAVID. These variables were vegetation indices, TPUs with high diversity of vegetation vigor yielded higher factor scores.

$BPCA5_{96}$ was water area due to its dominant and positively loadings on WATERM but negatively loading on URBANM. TPUs with high proportion of water area in rural area tended to fetch higher scores.

$BPCA6_{96}$ was surface temperature. The dominant loadings were positive related to TEMPERD and TEMPERM. TPUs with higher surface temperature had higher factor scores.

Table 4.7 illustrated the five principal components extracted from changes in the

Table 4.7. Principal components of biophysical variables extracted from changes in SPOT image (Varimax rotation converged in 7 iterations)

	Component					Communalities
	1	2	3	4	5	
ΔNDVID	**0.88**	-0.15	-0.03	0.07	0.06	0.81
ΔVEGD	**0.77**	-0.09	0.20	0.30	0.16	0.76
ΔWATERD	**0.77**	0.19	0.23	-0.04	-0.29	0.77
ΔSVI_5D	**0.68**	-0.38	-0.08	-0.10	0.12	0.64
ΔXS3D	**0.67**	0.38	0.31	-0.20	-0.07	0.74
ΔRVID	**0.63**	0.60	-0.32	-0.02	0.02	0.81
ΔNDVIM	-0.01	**0.91**	-0.34	0.05	-0.04	0.96
ΔRVIM	0.07	**0.89**	-0.39	-0.06	-0.02	0.95
ΔXS3M	-0.02	**0.87**	0.30	0.05	-0.07	0.86
ΔWATERM	0.06	**-0.71**	-0.10	-0.12	0.02	0.53
ΔXS2M	-0.04	-0.12	**0.94**	-0.08	-0.04	0.90
ΔXS1M	0.01	-0.28	**0.88**	0.02	-0.01	0.85
ΔXS2D	0.54	0.20	**0.71**	-0.10	0.11	0.86
ΔBARED	0.44	0.25	**0.66**	-0.24	0.08	0.75
ΔXS1D	0.58	0.11	**0.63**	-0.01	0.13	0.77
ΔSVI_5	-0.06	-0.02	-0.06	**0.85**	0.01	0.73
ΔVEGM	0.12	0.36	-0.15	**0.81**	-0.17	0.86
ΔURBAND	0.05	0.07	0.00	-0.20	**0.76**	0.62
ΔURBANM	-0.06	0.17	-0.03	-0.54	**-0.69**	0.80
ΔBAREM	-0.02	-0.27	0.55	-0.01	**0.55**	0.68
Eigenvalue	4.12	4.05	3.99	1.96	1.55	
% of Variance	20.58	20.24	19.96	9.80	7.77	

SPOT images, the difference between biophysical value of the 1997 SPOT and 1991 SPOT was used to derive the principal components for changes in biophysical variables. The five components represented 78.35% of the total variances which had a high explanation power.

The first component ($BPCA1_{9197}$) was interpreted as increase in diversity of vegetation cover. It was positively and heavily loaded on ΔNDVID, ΔVEGD, ΔWATERD, ΔSAVID, ΔXS3D and ΔRVID. Standard deviation of vegetation indices, vegetated area and near-infrared band represented the diversity of vegetation vigor. As aforementioned, XS3D was increased due to the increase mixing of fishponds and reservoirs with surrounding landuse and land cover which may be due to increased development in rural area. TPUs with higher factor scores represented an increase diversity of vegetation vigor.

The second component ($BPCA2_{9197}$) was increase in vegetation vigor because the dominant components like ΔNDVIM, ΔRVIM and ΔXS3M were positively loaded on this component while ΔWATERM has negative loadings. TPUs with increased in vegetation vigor and decreased in water area show higher factor scores.

The third component ($BPCA3_{9197}$) was interpreted as increase in soil brightness. It was positively dominated by loadings of ΔXS2M, ΔXS1M, ΔXS2D, ΔBARED and ΔXS1D. TPUs with increase in soil brightness showed higher factor scores.

The fourth component ($BPCA4_{9197}$) was also interpreted as increase in vegetation vigor, as it was positively dominated by the loadings of ΔSAVIM and ΔVEGM. TPUs with increase in vegetation vigor also yielded higher factor scores.

The fifth component ($BPCA5_{9197}$) was related to increase in urban area. It was positively and heavily loaded on Δ URBAND, Δ URBANM and Δ BAREM. TPUs with increase in urbanized area and vacant development land resulted in higher factor scores.

4.3 Summary

This chapter presented a general description of both socioeconomic and biophysical variables which would be used in later chapters for further analysis. Socioeconomic variables were extracted from census reports whilst biophysical variables were extracted by interpreting satellite imageries.

Considering the socioeconomic data, there were two data sets, i.e. the 1991 and the 1996 data sets which were extracted from 1991 census and 1996 by-census reports respectively. For each data set, there were 24 variables. Socioeconomic data of the 1991 data set can be re-grouped into six principal components explaining 78.57% of the total variance. These components were Purchasing Power ($SPCA1_{91}$), Working Force ($SPCA2_{91}$), Large Household Size ($SPCA3_{91}$), Working Age Group ($SPCA4_{91}$), Degree of Crowdedness ($SPCA5_{91}$) and Percentage of Home Ownership ($SPCA6_{91}$). For the 1996 data set, the variables were reduced to seven principal components namely Purchasing Power ($SPCA1_{96}$), Working Force ($SPCA2_{96}$), Large Household Size ($SPCA3_{96}$), Medium Sized Family ($SPCA4_{96}$), Working Age Group ($SPCA5_{96}$), Degree of Crowdedness ($SPCA6_{96}$) and Percentage of Home Ownership ($SPCA7_{96}$) which explained 77.54% of the total variance.

To derive biophysical data, both SPOT and Landsat TM images were used. Two SPOT images acquired in 1991 and 1997 and one Landsat TM image acquired in 1996 are used. Biophysical variables can be classified into five groups, i.e. raw data, landuse and land cover, vegetation indices, tasseled cap components and surface temperature. The last two groups were interpreted using Landsat TM image only. Principal component analysis results showed that there were three and five principal components derived from the 1991 and the 1997 SPOT images respectively. The first three components for the 1991 and 1997 data set were similar which were vegetation vigor (BPCA1), diversity of the vegetation (BPCA2) and soil brightness (BPCA3). The last two components of the 1997 data set were water area and diversity of urban area. The principal components analyzed using the 1991 and 1997 SPOT images explained 86.73% and 92.21% of the total variance.

Six components analyzed using the Landsat TM image represented 87.52% of the total variance. The components were soil brightness ($BPCA1_{96}$); vegetation vigor ($BPCA2_{96}$); diversity of soil brightness, ($BPCA3_{96}$); diversity of vegetation ($BPCA4_{96}$), water area ($BPCA5_{96}$) and surface temperature ($BPCA6_{96}$).

It was not difficult to find that the biophysical principal components for the 1991, 1996 and 1997 data sets consisted of similar components, i.e. vegetation vigor, diversity of vegetation vigor and soil brightness. Similarly, the socioeconomic principal components for the 1991 and 1996 data sets had some similar components including Purchasing Power, Working Force, Large Household Size, Working Age Group, Degree of Crowdedness and Percentage of Home Ownership.

The changes between the 1991 and the 1996 socioeconomic data sets showed that there are increase in labour participation, increase in less educated people, economic restructuring from secondary sector industry to tertiary sector industry and increase in purchasing power. For biophysical data, increase in vegetation vigor, diversity of vegetation, soil brightness and diversity of urban area were found between 1991 and 1997 data sets.

CHAPTER FIVE

INTERRELATIONSHIP BETWEEN SPECTRAL VARIABLES AND SOCIOECONOMIC VARIABLES

This chapter presented the correlation results of the relationship among socioeconomic and biophysical variables. Regression results of integrating SPOT and TM data with census data would also be analyzed and compared.

5.1 Framework of Analysis

Pearson Correlation coefficient are computed to generate correlation matrices among socioeconomic and biophysical data. Stepwise multiple linear regression modeling are then adopted to derive inter-relationship between the socioeconomic variables and biophysical data. In order to find out their relationships, four data sets were used in the regression models as illustrated in Table 5.1.

Table 5.1 Four data sets used in the stepwise multiple regression modeling

Integration		Abbreviation
Biophysical variables	Socioeconomic variables	
1991 SPOT	1991 census data	1991 data set
1996 SPOT	1996 by-census data	1996 data set
1997 SPOT	1996 by-census data	1997 data set
Difference between 1991 SPOT and 1997 SPOT	Difference between 1991 census and 1996 by-census data	1991-7 data set

Moreover, principal components of socioeconomic variables and principal components of biophysical variables which were identified using principal component analysis as presented in the Chapter Four, were also used as variables in the regression modeling processes.

Two approaches were adopted in the regression modeling to examine the relationship: (1) the spectral variables were used as the dependent variable (Y) and census data as the independent variables (X) and (2) census data were used as the dependent variable (Y) and spectral variables as the independent variables (X). The former showed how socioeconomic activities shape the environment whilst the latter showed whether environmental factors may exert any influence on socioeconomic development. Hence, there were eight sets of regression models. They were:

(1) Y = Biophysical variables, X = Socioeconomic variables;

(2) Y = Biophysical variables, X = Principal components of socioeconomic variables;

(3) Y = Principal components of biophysical variables, X = Socioeconomic variables;

(4) Y = Principal components of biophysical variables, X = Principal components of socioeconomic variables;

(5) Y = Socioeconomic variables, X = Biophysical variables;

(6) Y = Socioeconomic variables, X = Principal components of biophysical variables;

(7) Y = Principal components of socioeconomic variables, X = Biophysical variables; and

(8) Y = Principal components of socioeconomic variables, X = Principal components of biophysical variables.

The socioeconomic variables included all the extracted census data while the biophysical variables were those extracted from the satellite images for the respective years.

For each trial of stepwise regression modeling, one dependent variable (Y) was used together with a set of independent variables (X) as inputs. Independent variables were included in the equation if the probability of F-to-enter was less than or equal to 0.05. It was removed if the probability of F-to-enter was larger than or equal to 0.01. No equation would be formed when the probability of F-to-enter was less than or equal to 0.05. If an equation was formed, coefficient of determination (R^2) was the most important indicator for revealing the strength of the relationship of the model. Significance level should be less than 0.05 for the model to be accepted. In this study, a R^2 value greater than or equal to ± 0.4 was considered to have a significant relationship between the dependent and independent variables and vice versa.

Beta coefficient (β) is used to assess the contribution of each independent variable in the regression model (SPSS, 1998). It is also called the standardized regression coefficient. In other words, it is the regression coefficients when all variables were expressed in standardized (z-score) form. Transforming the independent variables to standardized form make the coefficients more comparable since they are all in the same unit of measurement (SPSS, 1999).

5.2 Correlation among Socioeconomic and Biophysical data

Pearson correlation is computed to assess the relationship between each pair of socioeconomic variable and spectral variable. Correlation coefficients, which were more than or equal to ±0.4 and significant at 0.01 level for two-tailed test, were extracted in Tables 5.2, 5.3 and 5.4 for the 1991, the 1996 and the 1997 data sets respectively. However, none of the correlation coefficients resulted from 1991-7 data set was more than or equal to ±0.4 and significant at 0.01 level for two-tailed test.

Pearson correlation results of 1991, 1996 and 1997 data sets had some common findings. For the sake of simplicity, only the common correlation findings were explained. It was found that population density and degree of crowdedness ($SPCA5_{91}$ and $SPCA6_{96}$) were negatively related to near infrared band (XS3M and TM4M) and the vegetation indices (NDVIM, RVIM and SAVIM). For instance, the correlation coefficients between population density and NDVIM were –0.643, -0.592 and –0.617 for the 1991, 1996 and 1997 data sets respectively. Since near infrared band had high reflectance for vegetation while NDVIM, RVIM and SAVIM were vegetation indices, the correlation results indicated that the higher the population density and degree of crowdedness, the lower the value of greenness was. The loading of $SPCA5_{91}$ was positively dominated by POP_DEN. Thus, $SPCA5_{91}$, to a large extent, was associated with population density and shows similar characteristics. From a cartographic analysis of NDVI (Figures 4.4, 4.5 and 4.6), it was noted that NDVI tended to be high in rural areas like country parks but low in urban areas like Mongkok, To Kwa Wan, Hunghom and the developed area on both sides of Victoria Harbour. Moreover, as shown in Figures 5.1, 5.2, 5.3 and 5.4, urban areas such as Chai Wan, Sham Shui Po, Mongkok, To Kwa Wan and Hunghom experienced high population density and a high degree of crowdedness. These areas were early developed areas with few green spaces preserved. These reasons supported the findings of having negative correlation between NDVI and population density. It

Table 5.2 Pearson Correlation Result between the socioeconomic data extracted from the 1991 census and the spectral variables from the 1991 SPOT

	WORK2	WORK3	A0-14	A40-54	HH6	POPDEN	$SPCA1_{91}$	$SPCA5_{91}$
XS2M	0.429							
XS3M			0.469	-0.466	0.458	-0.615		-0.545
URBANM			-0.403	0.438	-0.45	0.635		0.571
BAREM	0.512	-0.443					-0.449	
VEGM					0.403	-0.625		-0.563
NDVIM					0.414	-0.643		-0.571
RVIM						-0.603		-0.537
RVID						-0.460		
SAVIM					0.421	-0.650		-0.580

Only correlation coefficient having ≥ or ≤ 0.4 are shown
All correlation coefficient are significant at 0.01 level (two-tailed)

Table 5.3 Pearson Correlation Result between the socioeconomic data extracted from the 1996 by-census and the spectral variables from the 1996 TM

	WORK2	WORK3	INCOME	POP_DEN	$SPCA1_{96}$	$SPCA6_{96}$
TM4M				-0.405		-0.446
TM5M	0.432	-0.431			-0.445	
TM7M	0.400				-0.414	
WETM	-0.478	0.481	0.408		0.508	
GREENM				-0.562		-0.557
GREEND				-0.483		-0.409
URBANM				0.457		0.438
VEGM				-0.510		-0.525
VEGD				-0.443		-0.402
BAREM	0.434	-0.401			-0.451	
NDVIM				-0.592		-0.584
RVIM				-0.536		-0.542
RVID				-0.479		-0.439
SAVIM				-0.560		-0.566
SAVID				-0.428		

Only correlation coefficient having ≥ or ≤ 0.4 are shown
All correlation coefficient are significant at 0.01 level (two-tailed)

Table 5.4 Pearson Correlation Result between the socioeconomic data extracted from the 1996 by-census and the spectral variables from the 1997 SPOT

	POP_DEN	WORK2	WORK3	$SPCA1_{96}$	$SPCA6_{96}$
XS3M	-0.558				-0.520
URBANM	0.616				0.620
URBAND	-0.404				
VEGM	-0.593				-0.555
VEGD	-0.456				
BAREM		0.468	-0.455	-0.508	
NDVIM	-0.617				-0.585
RVIM	-0.596				-0.566
RVID	-0.471				
SAVIM	-0.616				-0.586

Only correlation coefficient having ≥ or ≤ 0.4 are shown

All correlation coefficient are significant at 0.01 level (two-tailed)

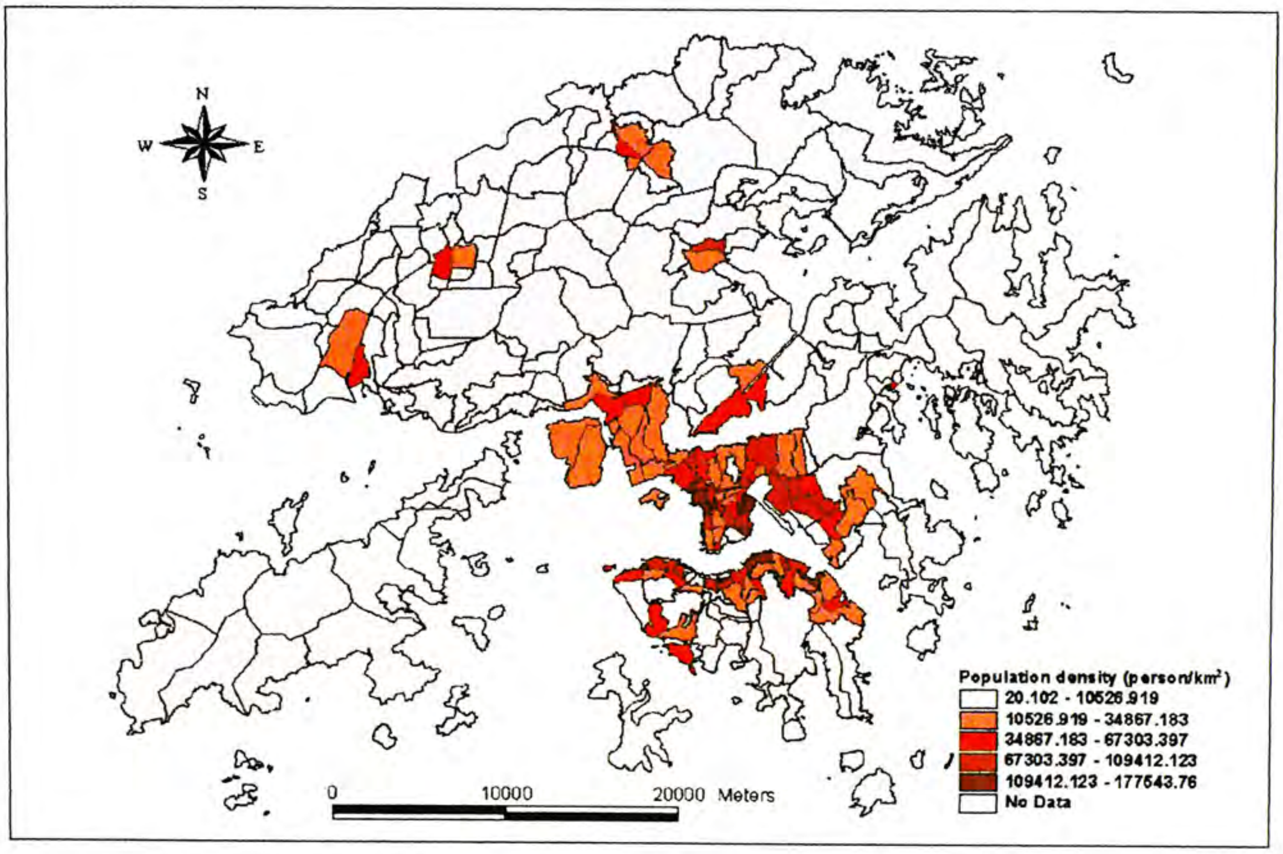


Figure 5.1 Population density in 1991

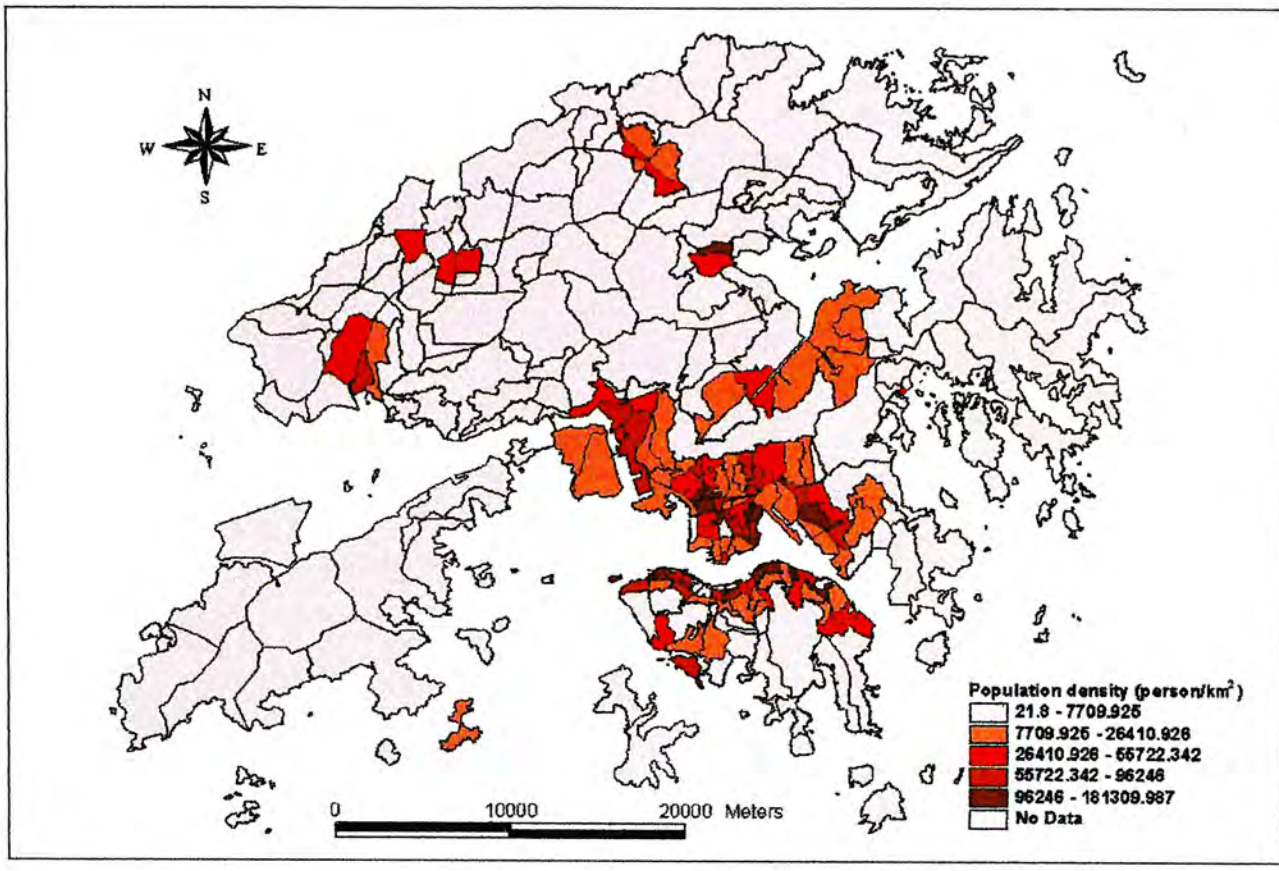


Figure 5.2 Population density in 1996

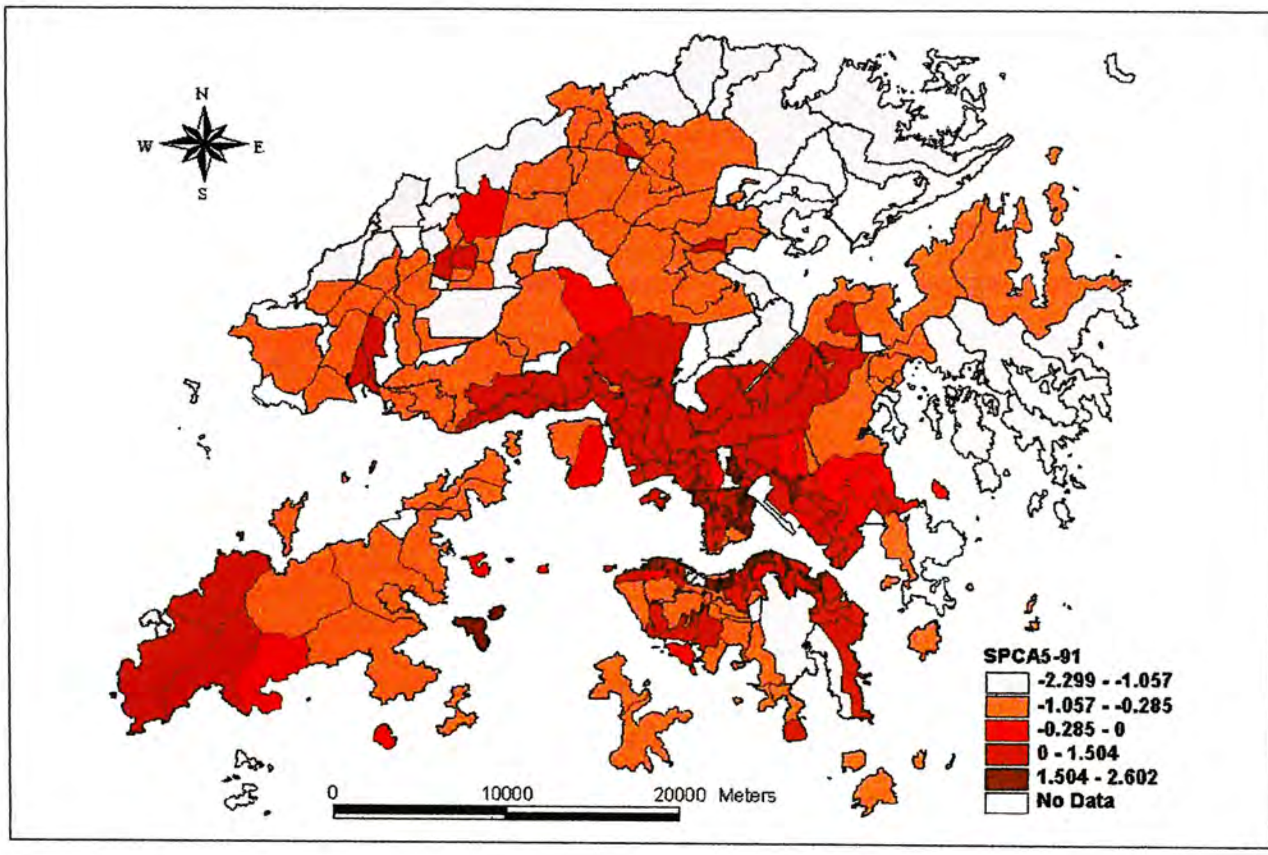


Figure 5.3 $SPCA5_{91}$ (Degree of crowdedness in 1991)

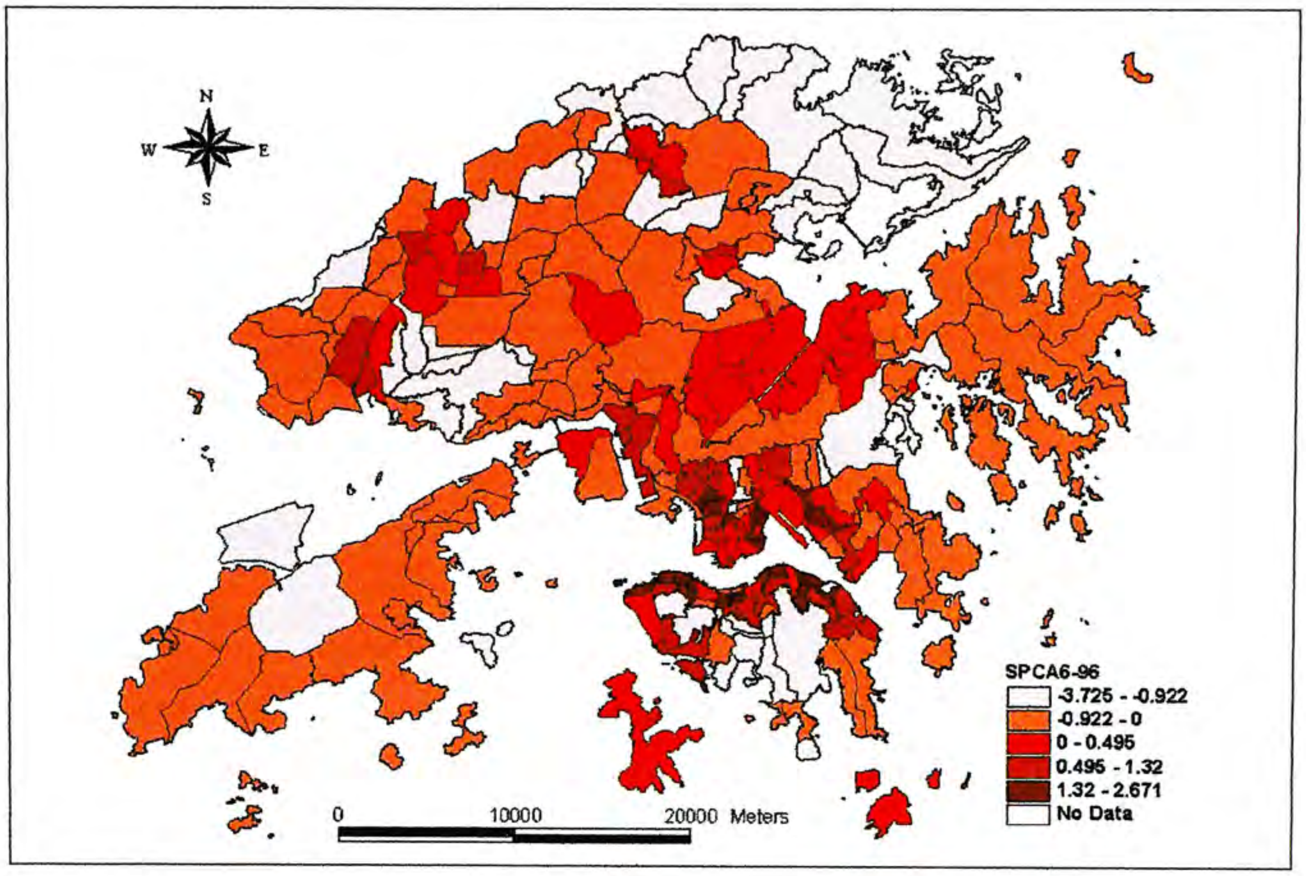


Figure 5.4 SPCA6$_{96}$ (Degree of crowdedness in 1996)

also deepened our understanding on the negative relationship between population density and vegetation. There were implications that if we used vegetation indices as environmental quality indicator like the study conducted by Fung and Siu (2000), rural areas would experience a better environmental quality, while the quality in urban areas are poor.

Moreover, diversity of vegetation like RVID and VEGD were negatively correlated to population density. For example, the correlation coefficients between RVID and population density were –0.460, –0.479 and –0.471 for the 1991, 1996 and 1997 data sets respectively. In some urban areas like Mongkok, Wan Chai, Sham Shui Po and Kwun Tong, green space were concentrated in urban parks and is rarely mixed with the buildings. Moreover, within areas having a large amount of vegetation cover like country parks, the variation of vegetation types would have positive effect on the diversity of vegetation indices.

Population density and degree of crowdedness ($SPCA5_{91}$ and $SPCA5_{96}$) were positively correlated to the mean of urban area (URBANM). For example, the correlation coefficient between $SPCA5_{91}$ and URBANM was 0.571. As mentioned above, the distribution of population density and degree of crowdedness were high in urban areas like To Kwa Wan, Wanchai, Mongkok, Hunghom, Sham Shui Po and new towns. In fact, urban areas acted as concentration nodes for population. It was obvious to detect a positive relationship between these two variables.

Although vacant development land (BAREM) were correlated to percentage of workers engaged in secondary sector (WORK2) and percentage of workers in tertiary sector (WORK3), a positive relationship was found for WORK2 while a negative relationship for WORK3. Since the secondary sector included construction and manufacturing industries, their working environment may be near the vacant development land and thus yielded a positive relationship. Tertiary works like sales, banking and financial were mainly in-house work located in business districts where buildings were close and dense.

Purchasing power ($SPCA1_{91}$ and $SPCA_{96}$) was negatively correlated to BAREM. As the positive loading of WORK3 and negative loading of WORK2 was high in purchasing power. WORK3 are low in BAREM as aforementioned and WORK2 was high in BAREM, it was reasonable that purchasing power was negatively correlated to BAREM.

The correlation result between SPOT and TM is similar which population density was negatively correlated to vegetation indices.

5.3 Stepwise Multiple Linear Regression Models

In this part, the results of multiple stepwise linear regression modeling were presented. General pictures of the modeling results were followed by a detailed explanation on selected models in the following sections.

5.3.1 Biophysical data as dependent variable

It was noted that very few models yielded a R^2 value greater than or equal to ±0.4 in the regression models. No model yielded a R^2 more than or equal to ±0.4 for the 1991-7 data set. Tables 5.5, 5.6 and 5.7 summarized the regression models for the 1991, 1996 and 1997 data sets respectively by using the spectral variables acquired from satellite sensors as dependent variable and all the 24 socioeconomic variables acquired from census data as independent variables. It was found that only fourteen, five and fifteen models had significant but not very strong relationship with socioeconomic variables for the 1991, 1996 and 1997 data sets respectively.

Using biophysical data as dependent variable, it was noted that there were two main categories of models found. These models used either vegetation indices or urban landuse as dependent variables. For vegetation indices, NDVI, RVI and SAVI were highly related to socioeconomic variables among all the regression models. This was evidenced that over 90% of the dependent variables were vegetation indices

Table 5.5 Regression models of biophysical factors as dependent variable for 1991 data set

	Relationship with Socionomic Variables							Relationship with Socionomic PCA Components						
X \ Y	XS3M	URBANM	NDVIM	RVIM	SAVIM	VEGM	$BPCA1_{91}$	XS3M	URBANM	NDVIM	RVIM	SAVIM	VEGM	$BPCA1_{91}$
POP_DEN	-0.500	0.560	-0.550	-0.508	-0.564	-0.584	-0.517							
A0-14			0.161	0.144	0.145									
A15-39														
A40-54	-0.310	0.287					-0.340							
a55	-0.148													
HH1		0.169	-0.545	-0.499	-0.548	-0.378								
HH2			0.214	0.212	0.199	0.120								
HH3														
HH4			-0.288	-0.268	-0.286	-0.121								
HH5	0.164						0.135							
HH6														
INCOME	0.291	-0.368	0.222	0.222	0.213	0.286	0.459							
WORK2			-0.246	-0.260	-0.242	-0.269								
WORK3														
PRO_LAB	-0.321	0.371	-0.548	-0.537	-0.503	-0.609	-0.409							
OWNER	0.127	-0.147				0.166	0.193							
M_LABOUR														
F_LABOUR														
BOTH_LABOUR	-0.132													
$SPAC1_{91}$								-0.236	0.154					-0.148
$SPAC2_{91}$								-0.206	0.224	-0.256	-0.237	-0.261	-0.269	-0.229
$SPAC3_{91}$								0.302	-0.249	0.229	0.199	0.232	0.221	0.248
$SPAC4_{91}$								0.235	-0.207	0.189	0.172	0.192	0.174	0.189
$SPAC5_{91}$								-0.542	0.574	-0.577	-0.543	-0.585	-0.572	-0.581
$SPAC6_{91}$								0.191	-0.251	0.246	0.233	0.239	0.250	0.242
R square	0.65	0.63	0.64	0.57	0.65	0.60	0.63	0.59	0.57	0.53	0.45	0.54	0.50	**0.56**

Value in the table indicates the Beta coefficients of the corresponding socioeconomic variables

Table 5.6 Regression models of biophysical factors as dependent variable for 1996 data set

	Relationship with Socionomic Variables				RSPCAC*
X \ Y	GREENM	NDVIM	SAVIM	$BPCA2_{96}$	$BPCA2_{96}$
POP_DEN	-0.481	-0.474	-0.468	-0.463	
A0-14		0.212			
A15-39		0.134			
A40-54			-0.278	-0.362	
A55	-0.142			-0.203	
HH1		-0.207			
HH2					
HH3				0.089	
HH4		-0.172			
HH5	0.131		0.250		
HH6	0.211	0.158		0.237	
INCOME		0.116	0.284	0.196	
WORK2					
WORK3					
PROF_LAB					
OWNER					
M_LABOUR	-0.161	-0.143	-0.290	-0.236	
F_LABOUR					
BOTH_LABOUR					
SEC					
TER					
MARRY			0.156	0.201	
$SPCA2_{96}$					0.130
$SPCA3_{96}$					0.166
$SPCA5_{96}$					0.142
$SPCA6_{96}$					-0.600
$SPCA7_{96}$					0.102
R square	0.42	0.49	0.46	**0.52**	**0.44**

* RSPCAC = Relationship with Socionomic PCA Components

Value in the table indicates the Beta coefficients of the corresponding socioeconomic variables.

Table 5.7 Regression models of biophysical factors as dependent variable for 1997 data set

	Relationship with Socioeconomic Variables							Relationship with Socioeconomic PCA Components				
	XS3M	URBANM	NDVIM	RVIM	VEGM	SAVIM	$BPCA1_{97}$	URBANM	NDVIM	VEGM	SAVIM	$BPCA1_{97}$
POP_DEN	-0.453	0.524	-0.491	-0.480	-0.441	-0.477	-0.466					
A0-14			0.263	0.168	0.432							
A15-39			0.275	0.223	0.407							
A40-54	-0.322	0.325				-0.329	-0.322					
A55	-0.263	0.277			0.256	-0.190	-0.360					
HH1	-0.325	0.108	-0.282				-0.190					
HH2	-0.199											
HH3												
HH4	-0.276		-0.265				-0.165					
HH5				0.169		0.151						
HH6		-0.105	0.154	0.180	0.153	0.123	0.196					
INCOME		-0.165			0.237	0.206						
WORK2												
WORK3												
PROF_LAB	-0.130	0.099					-0.107					
OWNER	-0.168		-0.147				-0.121					
M_LABOUR	-0.277		-0.357	-0.366	-0.358	-0.363	-0.217					
F_LABOUR	-0.225	0.201					-0.191					
BOTH_LABOUR												
SEC	-0.142		-0.114	-0.146	-0.124	-0.106	-0.117					
TER												
MARRY	0.410		0.222	0.229	0.223	0.214	0.326					
SEX_RATIO			-0.126									
$SPCA1_{96}$								0.162		0.114		-0.141
$SPCA2_{96}$								0.162	-0.173	-0.169	-0.172	-0.139
$SPCA3_{96}$								-0.193	0.151	0.131	0.153	0.175
$SPCA4_{96}$												
$SPCA5_{96}$								-0.255	0.169	0.181	0.167	0.214
$SPCA6_{96}$								0.620	-0.586	-0.555	-0.586	-0.610
$SPCA7_{96}$								-0.137	0.098	0.132	0.097	0.129
R square	0.56	0.64	0.56	0.50	0.51	0.56	0.63	0.56	0.43	0.42	0.43	**0.50**

All numerical values in the table are the Beta coefficient of the regression models.
Value in the table indicates the Beta coefficients of the corresponding socioeconomic variables

(NDVIM, RVIM and SAVIM) or the near infrared band (XS3M) which had high reflectance for vegetation. For example, the regression models for NDVIM yielded 0.64, 0.49 and 0.56 of R^2 value for the 1991, 1996 and 1997 data sets respectively. This phenomenon occurred in all regression models regardless whether the independent variables are raw socioeconomic variables or principal components. Regression models using NDVIM as dependent variable and socioeconomic variables or principal components of socioeconomic variables as independent variables were extracted for in-depth discussion in Section 5.3.1.1.

For urban landuse, URBANM were highly related to socioeconomic variables for the 1991 and 1997 data sets. For these two years, the R^2 is over 0.6 when URBANM was used as the dependent variable. Selected models were further discussed in section 5.3.1.2.

5.3.1.1 NDVI as dependent variable

As mentioned above, there were two categories of regression models found and "vegetation indices" was one of them. As a selected variable representing vegetation indices, NDVIM yielded a higher R^2 value than other vegetation indices, which were 0.64, 0.49 and 0.56 for the 1991, 1996 and 1997 data sets respectively. The independent variables of regression models using NDVIM as dependent variable were listed in Tables 5.8a and 5.8b.

From the Table 5.8a, it was found that NDVIM was related to POP_DEN, A0-14, HH1 and HH4 for all three data sets. Except A0-14, β of POP_DEN, HH1 and HH4 were negative in the equation. The highest loading came from POP_DEN.

Table 5.8 Regression models using NDVI as dependent variable and the socioeconomic data as independent variables

(a)	Data Set		
	1991	1996	1997
POP_DEN	-0.550	-0.474	-0.491
A0-14	0.161	0.212	0.263
HH1	-0.545	-0.207	-0.282
HH4	-0.288	-0.172	-0.265
A15-39		0.134	0.275
HH6		0.158	0.154
INCOME	0.222	0.116	
M_LABOUR		-0.143	-0.357
WORK2	-0.246		
PRO_LAB	-0.548		
HH2	0.214		
OWNER			-0.147
SEC			-0.114
MARRY			0.222
SEX_RATIO			-0.126
R square	**0.64**	**0.49**	**0.56**

*Value in the table indicates the β of the corresponding socioeconomic variable

(b)	Meaning of the principal components	Data set	
		1991	1997
$SPCA2_{91}$/ $SPCA2_{96}$	Working force	-0.256	-0.173
$SPCA3_{91}$/ $SPCA3_{96}$	Large household size	0.229	0.151
$SPCA4_{91}$/$SPCA5_{96}$	Working age group	0.189	0.169
$SPCA5_{91}$/$SPCA6_{96}$	Degree of crowdedness	-0.577	-0.586
$SPCA6_{91}$/$SPCA7_{96}$	Home ownership	0.246	0.098
R square		**0.53**	**0.43**

*value in the table indicates the β of the corresponding socioeconomic variable

Census data showed that high value for population density was found in Sham Shui Po, Mong Kok, To Kwa Wan, North Point, Sheung Wan and Tai Po whilst high value of HH4 was found in districts like Tuen Mun, Wong Tai Sin, Kwun Tong, Sai Wan Ho and Chai Wan. In short, HH4 and POP_DEN were high in urban areas but low in rural areas. NDVIM, however, were high in countryside especially in the County Parks that formed a contrast distribution with HH4 and POP_DEN. Hence negative loadings were found for HH4 and POP_DEN. Although the value of HH1 was high in urban districts locating at two sides of Victoria Harbour, a high value was also found in rural areas like Tin Shui Wan, Yuen Long, Sheung Shui, Fanling, Sai Kung and Lantau Island but low in areas where the Country Parks were found. This spatial distribution was different from that of NDVIM values so that a negative loading was found. A0-14 had a positive loading on equation, as aforementioned, young family tended to live in new towns where there were more green spaces. Thus, the loading of A0-14 was positive to NDVIM. In short, it was noted that population density and NDVIM showed dominant relationship.

Other variables contributing to NDVIM regression model and showing a positive relationship included A15-39, HH6, INCOME, OWNER, HH2 and MARRY. Meanwhile, M_LABOUR, WORK2, PROF_LAB, SEC and SEX_RATIO were showing negative relationship. However, these variables were found in only one regression model generated using the 1991, 1996 or 1997 data sets. They did not appear concurrently in all the regression models.

From Table 5.8b, it was found that the components of NDVI regression model for the 1991 and 1997 data sets were positively related to principal components of working age group, large household size and home ownership. As mentioned in previous section in this chapter, working age groups were mainly located in new towns where there was more vegetation cover. Large household size was usually located in rural areas and in the Mid-level. Home ownership was high in areas with higher NDVI, for example, they were located at the Mid-level, Kowloon Tong, rural areas in Northwest New Territories and new towns like Sheung Shui, Yuen Long, Shatin and Ma On Shan. Since residents in the Mid-level were mainly high income group, they may had the ability to own their houses while residents in rural area may own their 'small houses' as every local male residents in the villages in the New Territories had the right to own a house in their village. Moreover, new towns, which had a larger proportion of home owners and young age group, had more vegetation cover as mentioned before which resulted in negative relationship between NDVI and OWNER.

On the other hand, NDVI was negatively related to working force and degree of crowdedness as working force was mainly high in urban area especially in Wanchai, Chai Wan, Sham Shui Po and Mongkok. It was undoubtedly that these areas had lower vegetation cover and as aforementioned, degree of crowdedness was negatively related to NDVI.

5.3.1.2 URBANM as dependent variable

URBANM, another category of regression model using biophysical data as dependent variable, fewer regression models accepted as compared to that of NDVIM. Tables 5.9a and 5.9b illustrate the beta coefficient resulted by using URBANM as dependent variable and socioeconomic data as independent variables respectively. From Table 5.9a, it was noted that the common components for the

1991 and 1997 data sets were POP_DEN, A40-54, INCOME and PRO_LAB with a R^2 value of 0.63 and 0.64 respectively.

Population density, Age group of 40-54 and professional labour had positive and dominant loading in the equation. It was found that the values of POP_DEN, PROF_LAB, HH1 and A40-54 were high in urban areas like Tsuen Wan, Mong Kok, To Kwa Wan, Wan Chai and North Point etc. Adopting a concentrated development strategy in Hong Kong, only around 20% of the whole territory were developed as urban areas where were homes for over six million people. Since most Hong Kong citizens lived in urban areas resulting in a high population density, these positive loadings were not difficult to understand. Although more and more new towns were developed, old people tended to live in the old districts like Sham Shui Po, To Kwa Wan and Wan Chai resulting in high loading of A40-54 in URBANM. The correlation results among these variables presented in the previous section also highlighted this finding.

Income, however, had a negative loading. Since high income groups were mainly living in the Mid-level, the Peak, the Southern district, Fairview Park and Sai Kung where the population density was lower with more green space, a negative loading reflected this distribution. Moreover, high-income groups were more mobile to move out from urban core areas and seek for a better living environment with less population density and more green space.

When PCA of socioeconomic variables were used as independent variables in the regression models, it was found that URBANM was positively related to purchasing power, working force and degree of crowdedness. These three principal

Table 5.9 Regression models using URBANM as dependent variable and the socioeconomic data as independent variables

(a)	Data set	
	1991	1997
POP_DEN	0.560	0.524
A40-54	0.287	0.325
INCOME	-0.368	-0.165
PRO_LAB	0.371	0.099
HH1	0.169	0.108
A55		0.277
HH6		-0.105
OWNER	-0.147	
F_LABOUR		0.201
R square	**0.63**	**0.64**

* value in the table indicates the β of the corresponding socioeconomic variable

(b)	Meaning of the principal components	Data set	
		1991	1997
$SPCA1_{91}$/ $SPCA1_{96}$	Purchasing power	0.154	0.162
$SPCA2_{91}$/ $SPCA2_{96}$	Working force	0.224	0.162
$SPCA3_{91}$/ $SPCA3_{96}$	Large household size	-0.249	-0.193
$SPCA4_{91}$/$SPCA5_{96}$	Working age group	-0.207	-0.255
$SPCA5_{91}$/$SPCA6_{96}$	Degree of crowdedness	0.574	0.620
$SPCA6_{91}$/$SPCA7_{96}$	Home ownership	-0.251	-0.137
R square		**0.57**	**0.56**

*value in the table indicates the β of the corresponding socioeconomic variable

components mainly reflected the demographic and economic characteristics of Hong Kong population. High value was found in urban areas but low in rural areas since urban areas were population concentration nodes where working force with higher purchasing power resided. Working age group, large household size and home ownership showed negative loadings in the regression models. As stated in the previous section, high value of these three components was found in rural areas rather than urban areas. On the other hand, the working age group was mainly located in Ma On Shan and Sham Tseng-Siu Lam where less development was observed. Home ownership was concentrated in northwestern and northeastern New Territories. The loadings of these components on regression model were thus negative.

5.3.2 Socioeconomic data as dependent variable

Tables 5.10, 5.11 and 5.12 presented the regression models using socioeconomic variables as dependent variable and biophysical variables as independent variables. It was found that, similarly, there was no regression model yield a R^2 greater than or equal to ±0.4 for the 1991-7 data set. The number of regression models was only two, one and three for the 1991, 1996 and 1997 data sets respectively.

It was noted that all the dependent variables were population density except one for $SPCA6_{96}$ which was representing degree of crowdedness in the 1997 data set. Moreover, the independent variables for these models were different but NDVIM was found in every model. The negative relationship between population density and NDVI was clearly shown in these models.

5.3.2.1 POP_DEN as dependent variable

From Tables 5.10, 5.11 and 5.12, it clearly showed that the major and common component of POP_DEN regression model were vegetation indices, more specifically NDVIM. The loading of NDVIM was negative. This result of negative loading was not surprised as this negative relationship had been observed in the correlation results and regression models using vegetation index as dependent

Table 5.10 Regression models of the socioeconomic data as the dependent variable for the 1991 data set

Dependent	RSBPV*	RSPCAC**
Independent	POP_DEN	POP_DEN
XS2M	-0.207	
NDVIM	-0.763	
$BPCA1_{91}$		-0.609
$BPCA2_{91}$		-0.180
R square	**0.420**	**0.420**

* RSBPV = Relationship with Biophysical Variables

** RSPCAC = Relationship with Biophysical PCA Components

Table 5.11 Regression models of the socioeconomic data as the dependent variable for the 1996 data set

Dependent	RSBPV *
Independent	POP_DEN
NDVIM	-0.821
BAREM	-0.394
TM4M	0.225
R square	**0.424**

* RSBPV = Relationship with Biophysical Variables

Table 5.12 Regression models of the socioeconomic data as the dependent variable for the 1997 data set

Dependent	RSBPV*		RSPCAC*
Independent	$SPCA6_{96}$	POP_DEN	POP_DEN
URBANM	0.399		
NDVIM	-1.366	-0.763	
XS1M	-0.760	-0.213	
XS3M	-0.736		
$BPCA1_{97}$			-0.632
$BPCA2_{97}$			-0.224
$BPCA3_{97}$			-0.129
R square	**0.422**	**0.405**	**0.467**

* RSBPV = Relationship with Biophysical Variables

** RSPCAC = Relationship with Biophysical PCA Components variable. Another common component of the regression model was $BPCA1_{91}$ and $BPCA_{97}$. $BPCA1_{91}$ and $BPCA_{97}$ were defined as vegetation vigor which had close and similar distribution pattern to NDVIM. It came to a conclusion that population density was strongly and negatively related to vegetation vigor.

5.4 Discussions and Conclusion

This chapter had presented the interrelationship among socioeconomic and biophysical variables using correlation and stepwise linear multiple regression. For correlation analysis, TM and SPOT yielded similar result which NDVI, SAVI and RVI were negatively related to population density and URBANM. For the regression analysis, TM and SPOT also yielded similar result which vegetation indices were negatively related to population density. However, the integration using SPOT data tended to yield more regression models with R^2 more than ±0.4.

Using biophysical data as dependent variables, there were two major categories of regression models found. In other words, either the proportion of urban area or vegetation indices was used as dependent variables. Taking socioeconomic data as dependent variables in regression modeling, only one main category, population density, was significant.

It was found that vegetation indices such as NDVI, SAVI and RVI were common dominating factors in regression models using either URBANM or POP_DEN as dependent variables. Similarly, population density was the dominant component in regression models using vegetation index as dependent variable. Population density and vegetation vigor had significant negative relationship. It was not difficult to understand that a crowded TPU should had less open space for vegetation. This result agreed with previous findings by Fung and Siu (2000) that the mean of NDVI had a negative relation with population density.

NDVIM could thus be used to assess biophysical environmental quality in terms of the proportion of green space in TPUs. It could also reflect the socioeconomic condition in terms of whether space was crowded with population or little vegetation cover in those old urban core areas. On the other hand, population density could also be used to assess the quality of both socioeconomic and biophysical environments.

Although only population density and vegetation vigor were found inter-related in regression modeling, it did not mean that other variables such as income, education level, temperature stress and urban landuse were not useful in QOL analysis. Indeed, uncorrelated variables of regression models represented different scopes and dimensions of socioeconomic and biophysical environments. They interactively shaped the quality of our living environment, our perception on environment, our satisfactory and ultimately our life quality. In order to have a more comprehensive QOL study, these data should not be excluded. Therefore, variables representing different dimensions of socioeconomic and biophysical environments were selected in evaluating the objective quality of life in Chapter Six.

CHAPTER SIX QUALITY OF LIFE ANALYSIS

Hong Kong is a very small place with limited land resources and yet, she faces tremendous development pressures. Over the past three decades, Hong Kong people have benefited significantly from the territory's miraculous economic development, modernization and urbanization. People are benefited from the rising education level and improving living environment through rejuvenating inner city on the one hand but have to worry more about deteriorating air quality and water quality resulted from development on the other hand. What is the impact of these changes on the quality of life of Hong Kong people? Objective statistics are indispensable for understanding the societal well beings. This chapter presented an overview of the key findings of spatio-temporal variations of Quality of life (QOL). These findings were acquired using Principal Components Analysis (PCA) of the selected socioeconomic and biophysical variables.

6.1 Selection of variables to derive QOL indicators

As mentioned in Chapter Four, socioeconomic variables were reduced to six and seven components for the 1991 and 1996 census data using PCA respectively. Similarly, biophysical variables were reduced to three, six and five components for the 1991 SPOT, the 1996 Landsat TM and the 1997 SPOT data sets respectively. Aiming to derive the life quality indicators through integrating the socioeconomic and biophysical components, one representative variable was selected from every component instead of the component itself to avoid errors of putting orthogonal principal components into further linear transformation. These representative variables were then analyzed using PCA to derive objective QOL indicators. These representative variables and their corresponding components were listed in Table 6.1.

The selection of these representative variables was based on the dominating factor in their corresponding components. The dominating factor was determined based on two criteria: either (1) using the variable with the highest loading in the principal component or (2) the variable that had a high loading and could best represent the meaning of that principal component. In order to make QOL indicator comparison possible, only three representative biophysical variables were selected from the 1997 data set instead of five by excluding $BPCA4_{97}$ and $BPCA5_{97}$. Similarly, $SPCA4_{96}$ was not included for QOL analysis for the 1996 data set. The details of these variables and their significance to QOL analysis were explained in Table 6.2.

Table 6.1 Variables selected for objective QOL analysis.

	Socioeconomic Environment		Biophysical Environment	
	Component	Representative variables	Component	Representative variables
1991 Data set	1. Purchasing Power	INCOME	1. Vegetation vigor	NDVIM
	2. Working Force	BOTH_LAB	2. Diversity of vegetation	NDVID
	3. Large Household Size	HH5	3. Soil Brightness	BAREM
	4. Working Age Group	A15-39		
	5. Degree of Crowdness	POP_DEN		
	6. Home Ownership	OWNER		
1996 Data set	1. Purchasing Power	INCOME	1. Soil brightness	SOILM
	2. Working Force	BOTH_LAB	2. Vegetation vigor	NDVI
	3. Large Household Size	HH5	3. Diversity of soil brightness	SOILD
	4. Medium Size Family	---	4. Diversity of vegetation	NDVID
	5. Working Age Group	A15-39	5. Water area	WATERM
	6. Degree of Crowdness	POP_DEN	6. Surface temperature	TEMPERM
1997 Data set	7. Home Ownership	OWNER	1. Vegetation vigor	NDVIM
			2. Soil Brightness	BAREM
			3. Diversity of vegetation	NDVID
			4. Water area	---
			5. Diversity of urban area	---

Temporal changes between 1991 and 1997 data set	1. Increase in labour participation → △BOTH_LAB 2. Increase in elementary education attainment → △ELEM 3. Economic restructuring from secondary to tertiary industry → △WORK3 4. Increase in purchasing power → △INCOME 5. Increase in household size → △HH4 6. Increase in female participation → △F_LABOUR 7. Decrease in children population → △A0-14 8. Improvement in living space → △POP_DEN	1. Increase in diversity of vegetation → △NDVID 2. Increase in vegetation vigor → △NDVIM 3. Increase in soil brightness → △XS2M 4. Increase in vegetation vigor → △SVIM 5. Increase in diversity of urban area → △URBAND

△ refers to the temporal changes of the variables from 1991 to 1996

Table 6.2 Socioeconomic variables to be included in QOL analysis

Variables		Data set	Indication
SOCIOECONOMIC	INCOME	1991 1996 1997	TPU where people with higher average median household income can afford and will find a living place with better quality of life. They will feel more stable with less financial constraints.
	BOTH_LAB	1991 1996 1997	Household income will increase if both the husband and wife of a family are working. With increase in income, QOL improves.
	HH5	1991 1996 1997	Foo (2000) and Leelakulthanit and Day (1992) found that the mean QOL score increase with higher household size in Singapore and Thailand respectively. This variable is used in this study to examine whether their arguments are valid in Hong Kong.
	A15-39	1991 1996 1997	This indicates the young working group whose career path has just started and their income is expected to be low. Wan (1991) also stated that young people will have more stress on money and employment
	POP_DEN	1991 1996 1997	Population density shows the degree of crowdedness, QOL is expected to be low when people are living in a crowded environment. Fadda and Jiron (1999) stated that city which is characterized by a high concentration of population and economic activities with a concentrated urban development pattern, has had a negative effect on environmental quality
	OWNER	1991 1997	In a Chinese society, home ownership is a traditional practice that brings satisfaction to home owners. It fosters social stability, sense of belonging and help provide future financial security to the family. Moreover, home owners will have a sense of independence as well as control over their own homes (Chiu, 1998). Wan (1991) also finds that home ownership occupies an enduring and important place in structuring QOL.
BIOPHYSICAL	NDVIM	1991 1996 1997	Previous researches from Lo (1997), Lo and Faber (1997) and Fung and Siu (2000) have shown that vegetation indices are positively related to quality of life and environmental quality.
	NDVID	1991 1996 1997	
	BAREM	1991 1997	From principal components extracted in Chapter Four, BAREM, SOILD, WATERM and TEMPERM represent some characteristics of the biophysical environment. Their influences on QOL, however, are rarely discussed in previous studies. In this study, they are introduced in the QOL indicator generation to find out whether they would interact with other variables on QOL.
	SOILM	1996	
	SOILD	1996	
	WATERM	1996	
	TEMPERM	1996	

6.2 QOL indicators

Based on the rule that the minimum eigenvalue should not be less than 1, three, four and six principal components were extracted for the 1991, 1997 and 1996 data sets respectively (Table 6.3). In 1991, three components together explained over 55% of the total variance among the indicators. In 1997, four components explained around 69% of the total variance whilst six components explained about 74% of the total variance.

It was found that the loading values of component 1 (QOL1) for all the 1991 (QOL1-91), 1996 (QOL1-96) and 1997 (QOL1-97) data sets were strongly and positively related to NDVIM but negatively related to POP_DEN. This finding indicated that NDVIM was high with low level of population density. It was, thus, interpreted as degree of vegetation vigor. TPU with higher degree of vegetation vigor and lower population density yielded a higher factor score. As stated in Table 6.2, NDVI had a positive contribution while population density had a negative contribution to QOL. QOL1 was a positive indicator of quality of life explaining the physical environmental and socioeconomic life quality.

Table 6.3 Principal component analysis for years (a) 1991, (b) 1997 and (c) 1996

	Component			
(a)	1	2	3	Communalities
NDVIM	**0.90**	-0.13	-0.01	0.831
POP_DEN	**-0.75**	0.05	-0.03	0.568
BAREM	**-0.56**	-0.39	0.37	0.598
NDVID	**0.51**	-0.01	0.41	0.435
INCOME	0.29	**0.81**	0.04	0.733
BOTH_LAB	-0.13	**0.72**	-0.09	0.546
A15_39	0.21	**-0.51**	-0.19	0.336
HH5	0.19	-0.05	**0.73**	0.557
OWNER	0.14	-0.15	**-0.66**	0.474
Eigenvalue	2.14	1.62	1.32	
% of Variance	23.81	17.99	14.63	

	Component				
(b)	1	2	3	4	Communalities
NDVIM	**0.87**	0.01	-0.21	-0.01	0.79
POP_DEN	**-0.82**	-0.03	-0.15	-0.26	0.75
NDVID	**0.71**	0.01	-0.05	-0.25	0.56
BOTH_LAB	-0.10	**0.73**	0.04	0.36	0.68
INCOME	0.16	**0.72**	-0.38	0.02	0.68
HH5	0.22	**0.70**	0.15	-0.31	0.66
A15_39	0.33	**-0.51**	0.10	0.20	0.42
BAREM	-0.06	-0.07	**0.96**	0.00	0.93
OWNER	0.01	-0.04	-0.01	**0.88**	0.77
Eigenvalue	2.11	1.82	1.17	1.16	
% of Variance	23.41	20.17	13.00	12.88	

(c)	Component						Commu-nalities
	1	2	3	4	5	6	
NDVIM	**0.89**	0.06	-0.22	-0.01	-0.06	0.00	0.84
POP_DEN	**-0.83**	-0.01	-0.13	-0.11	-0.18	0.09	0.76
BOTH_LAB	-0.14	**0.78**	0.05	0.03	0.29	-0.10	0.72
INCOME	0.13	**0.77**	-0.20	0.07	-0.09	-0.06	0.67
HH5	0.27	**0.64**	0.13	-0.21	-0.24	0.19	0.64
A15_39	0.23	**-0.43**	0.09	0.39	0.16	-0.14	0.44
SOILM	0.10	-0.12	**0.82**	-0.07	0.05	0.30	0.79
SOILD	-0.19	0.04	**0.79**	0.11	-0.14	-0.31	0.79
WATERM	-0.03	-0.03	0.00	**0.89**	0.09	0.07	0.81
NDVID	0.50	0.05	0.01	**0.58**	-0.33	-0.03	0.69
OWNER	0.07	-0.02	-0.06	0.04	**0.90**	-0.01	0.83
TEMPER	-0.09	0.01	0.02	0.04	-0.02	**0.93**	0.87
Eigenvalue	1.94	1.82	1.43	1.37	1.17	1.13	
% of Variance	16.18	15.17	11.89	11.39	9.73	9.40	

Second component (QOL2) was interpreted as purchasing power. It possessed a strong positive loading on INCOME and BOTH_LAB for the 1991, 1996 and 1997 data sets. Meanwhile, a negative loading on A15-39 was found. For the 1996 and 1997 data sets, a strong positive loading on HH5 was also observed. BOTH_LAB and INCOME had a positive meaning to QOL while A15-39 had a negative meaning to QOL as stated in Table 6.2. This principal component extracted can be regarded as a positive QOL indicator showing the purchasing power. TPU with a high proportion of population who yielded higher income, both labour participation and low proportion of population aged 15-39 yielded a higher factor score which showed a better QOL.

Components 5 and 4 for the 1996 and 1997 data sets respectively (i.e. QOL5-96 and QOL4-97) had high loadings on OWNER. As mentioned in Table 6.2, increase in home ownership would foster social stability, enhance the sense of satisfaction, independence and belonging of the owners. It in turn increased the overall satisfaction of the owners and thus leaded to an increase in QOL. Home ownership could therefore act as a positive QOL indicator. TPU with higher proportion of population who were home owners shows a better QOL and yielded a higher factor score.

Component 3 for the 1991 data set was positively and dominantly loaded on HH5 but negatively loaded on OWNER. As mentioned in Table 6.2, both HH5 and OWNER should have a positive effect on QOL. It, however, showed a contradictory result. Although it represented some characteristics of demographic and economic aspects of Hong Kong, it was not regarded as a QOL indicator in this study.

Component 3 for the 1997 data set showed a strong loading on BAREM only which indicated that it reflected the characteristics of vacant development land. It represented the large scale of urban development activities like the construction of the new airport in the mid-1990s. Similarly, components 3, 4 and 6 had a significantly positive loading on SOIL (i.e. both SOILM and SOILD), WATERM, OWNER and TEMPER respectively for the 1996 data set. In other words, these components represented soil brightness, water area and surface temperature respectively. Although they showed some characteristics of the biophysical environment, their impacts on QOL were unclear and cannot be regarded as QOL indicator. For example, the major impact of surface temperature on QOL was temperature stress which referred to temperature that was too high or too low or temperature fluctuation in a short time. However, surface temperature extracted from Landsat TM imagery in this study only revealed the condition of a point in time and hence temperature fluctuation cannot be studied. Moreover, surface temperature extracted falled in the range of 15-22°C which was quite normal in Hong

Kong and cannot show how it affected QOL.

It was noted that only components 1 for all the 1991, 1996 and 1997 data sets consisted of loadings from socioeconomic and biophysical variables. Component 2 consisted of loadings from socioeconomic variables only. QOL4-97 and QOL5-96 also had loading from the socioeconomic variable, OWNER. It was found that only one QOL indicator included both socioeconomic and biophysical variables while other indicators included either socioeconomic or biophysical variables but not both. Apart from integrating the biophysical and socioeconomic data, either the biophysical or socioeconomic data alone could still be regarded as QOL indicators.

6.3 Spatial variation of QOL

QOL indicators were mapped to digital TPUs for respective years using ArcView GIS so that spatial variation of QOL could be studied. Figures 6.1, 6.2 and 6.3 illustrated the first QOL1 for years 1991, 1996 and 1997 respectively. It was found that general spatial distribution pattern of component factor score was similar and consistent. Since QOL1 represented vegetation vigor, the higher positive QOL1 factor score, the more desirable and the better for the QOL. In other words, areas with negative factor score had experienced less desirable and poorer QOL. From these figures, it was discovered that positive value was associated with rural areas while negative value was found in urban areas. Tai Mo Shan, Sai Kung and NW coastal areas like Mai Po yielded a positive factor score. The factor score for urban area, however, was negative. It indicated that people in rural areas experienced a higher QOL than people living in urban areas.

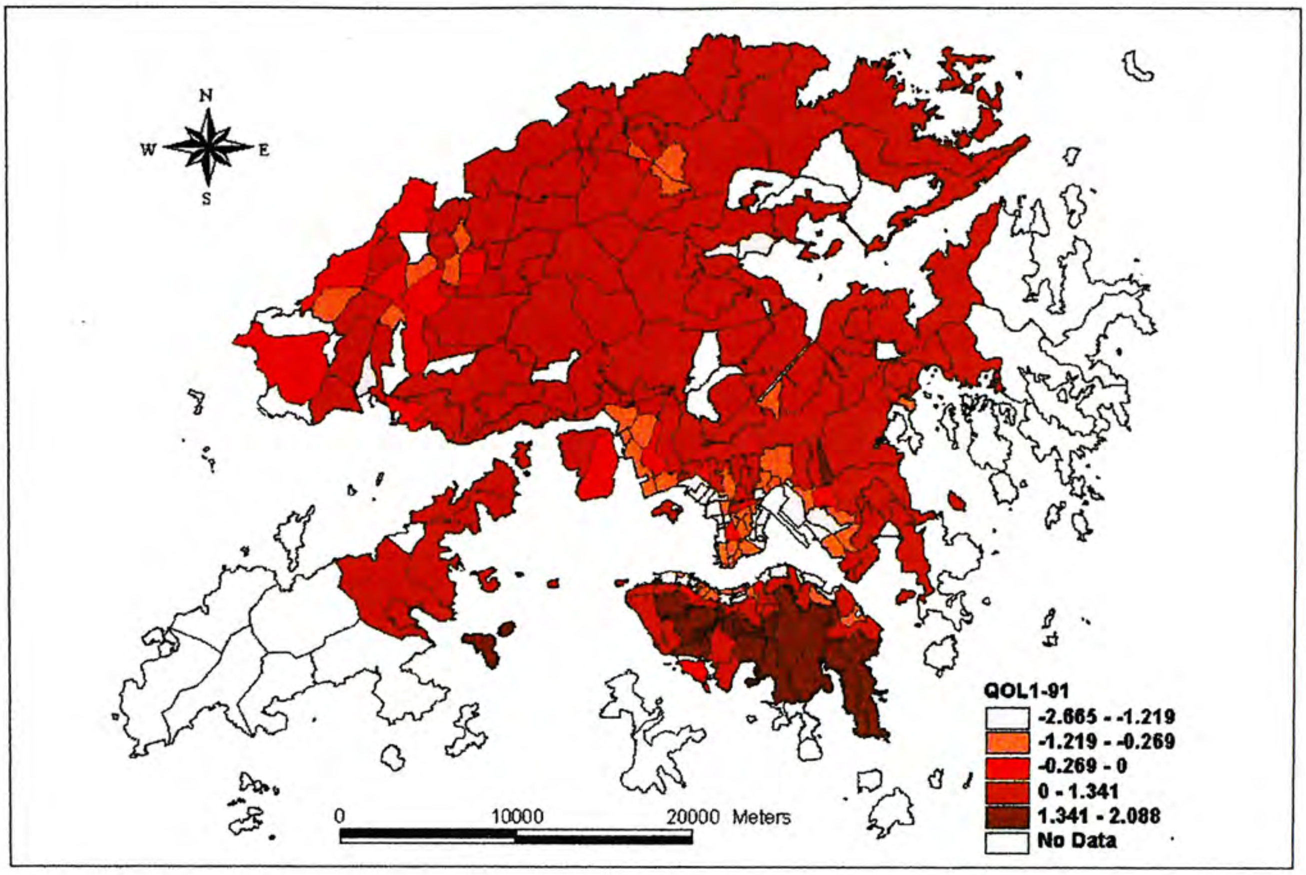


Figure 6.1 QOL1-91 (vegetation vigor in 1991)

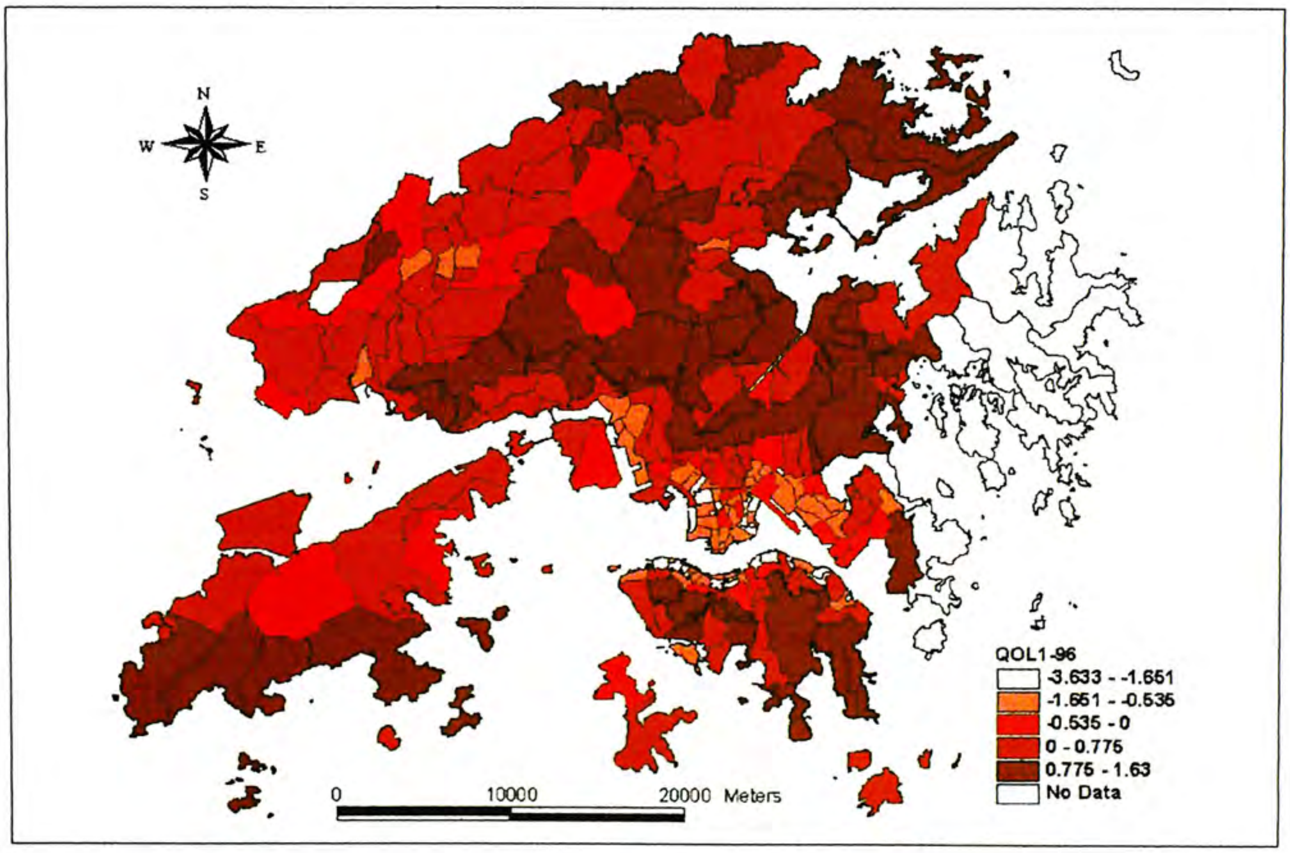


Figure 6.2 QOL1-96 (vegetation vigor in 1996)

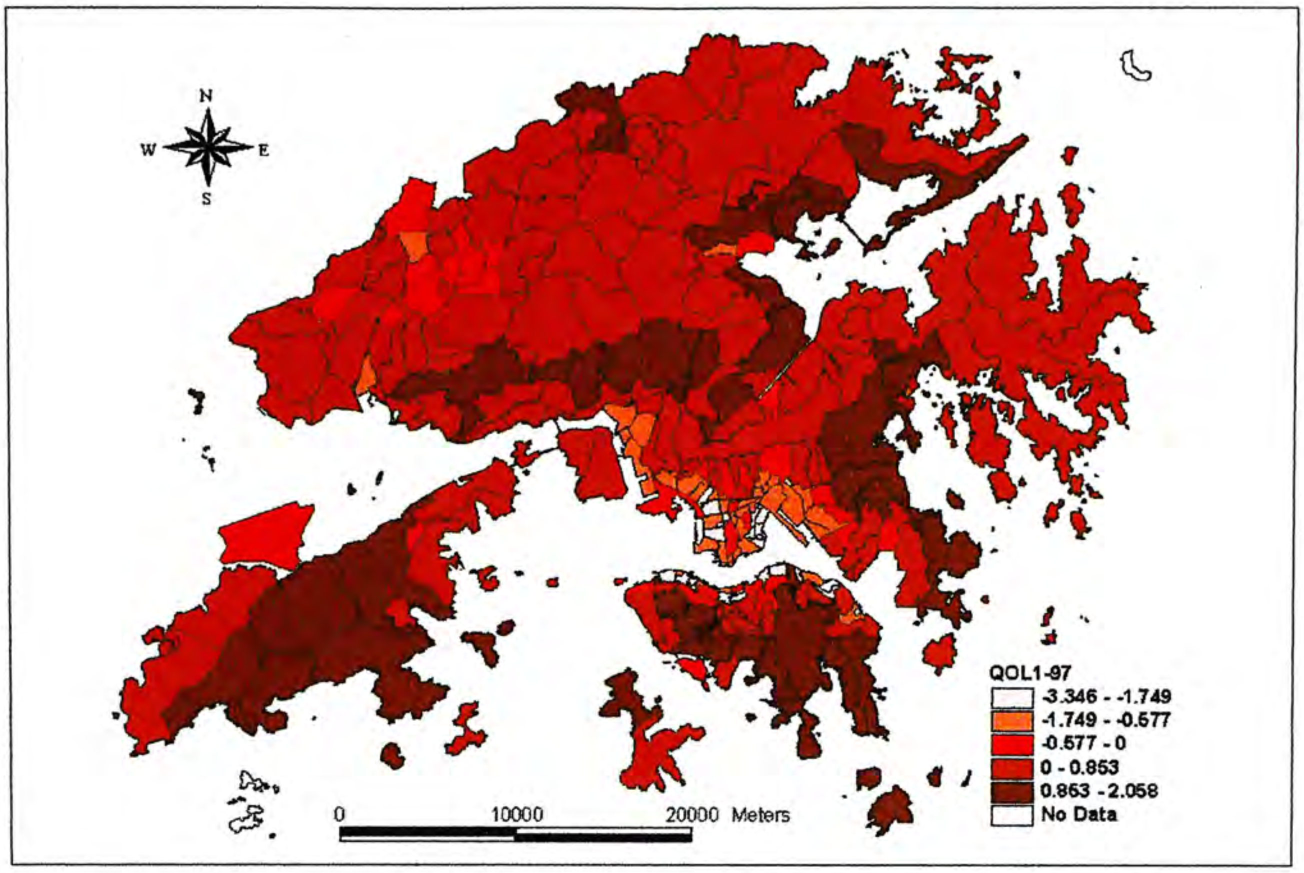


Figure 6.3 QOL1-97 (vegetation vigor in 1997)

This result was understandable as vegetation cover is relatively abundant in rural areas where less urban development was found and the natural landscape was preserved. For example, Mai Po is designed as a conservation area where development is restricted. As Hong Kong's backyard garden, Sai Kung is planned and developed as a low-density region performing mainly recreational function with a higher QOL.

It was important to note that not everywhere in the metropolitan areas experienced poor QOL in terms of paucity in green space. Kowloon Tong and Happy Valley, for example, were exceptional cases. The factor score for Kowloon Tong, the Mid-level and Happy Valley was positive. This indicated that the QOL for these districts was the best among the metropolitan areas and people living there experienced a more desirable QOL than people living in other metropolitan areas.

Moreover, in areas near the parks such as the Victoria Park and Hong Kong Park, a relatively high QOL factor score was found. Since QOL1 was related to greenness and population density, residences in these areas with positive factor scores experienced a better QOL. However, QOL for people in Kowloon Tong and Happy Valley was still lower than that in non-urban areas.

Although new towns like Shatin, Tai Po, Sheung Shui-Fanling, Yuen Long, Tseung Kwan O and Tin Shui Wai were also classified as urban areas, the QOL there were more desirable than in metropolitan areas as reflected by the factor scores. Since these new towns were developed with the objective of better planning and better landscaping so as to improve QOL, green space was a part of consideration in development planning that resulted in a better QOL in new towns than metropolitan areas. On the other hand, improper landuse planning in the old metropolitan areas led to high density high rise development with few green space.

However, there were variations among the years of 1991, 1997 and 1996. In 1991, the high positive factor scores were found in Tai Mo Shan, Pat Sin Leng, Sai Kung, Tung Chung, Shek O, Wong Chuk Hang and the Southern District. Similar conditions were found in 1996 and 1997. These areas were mainly less populated and less developed areas where hills and country parks were mainly covered by woodland. As an indicator of vegetation vigor, the value of NDVI was affected by climatic condition and hill fires of the year when the satellite image was acquired. The dates of image acquisition for Landsat TM and SPOT imageries were different. The former was acquired in March while the latter was taken in December. Growth condition of vegetation was thus different which may result in different NDVI values.

Figures 6.4, 6.5 and 6.6 presented QOL2 for data set of 1991, 1996 and 1997 respectively. As explained in previous section, QOL2 represented purchasing power. The higher the factor score, the more desirable the QOL. It was noted that the highest score was found in the Mid- Level and southern part of Hong Kong for the 1991, 1996 and 1997 data sets. However, the positive scores extended to Sai Kung, Shatin, Cove Hill, Discovery Bay and Sham Tseng in 1996. It was further extended to northern New Territories. Since areas like the Mid-Level, southern part of Hong Kong, Sai Kung, Discovery Bay, Pok Fu Lam and Sham Tseng were mainly areas where high income group resided, the pattern was reasonable. It was found that the poorest QOL regions were in rural areas for all three study years as the scores were negative. Since the loading of QOL2 mainly came from BOTH_LAB and INCOME, INCOME was high in urban areas as shown in Figures 6.7 and 6.8. BOTH_LAB were mostly located in urban areas like Sham Shui Po and Chai Wan. It was low in rural areas as illustrated in Figures 6.9 and 6.10.

Figures 6.11 and 6.12 showed QOL5-96 and QOL4-97 which represented home ownership for 1996 and 1997 respectively. For home ownership, the higher the factor score the better the QOL is. It was noted that QOL in rural areas was better than that in urban areas in both 1997 and 1996. As shown in Figures 6.13 and 6.14 referring to percentage of home ownership in 1991 and 1996 respectively, higher percentage of ownership was found in rural area, the pattern was similar to Figures 6.11 and 6.12 showing the scores of QOL5-96 and QOL4-97. People in rural areas were mainly local villagers who owned their "small houses" and high-income group had their purchased houses. However, a large proportion of population rented

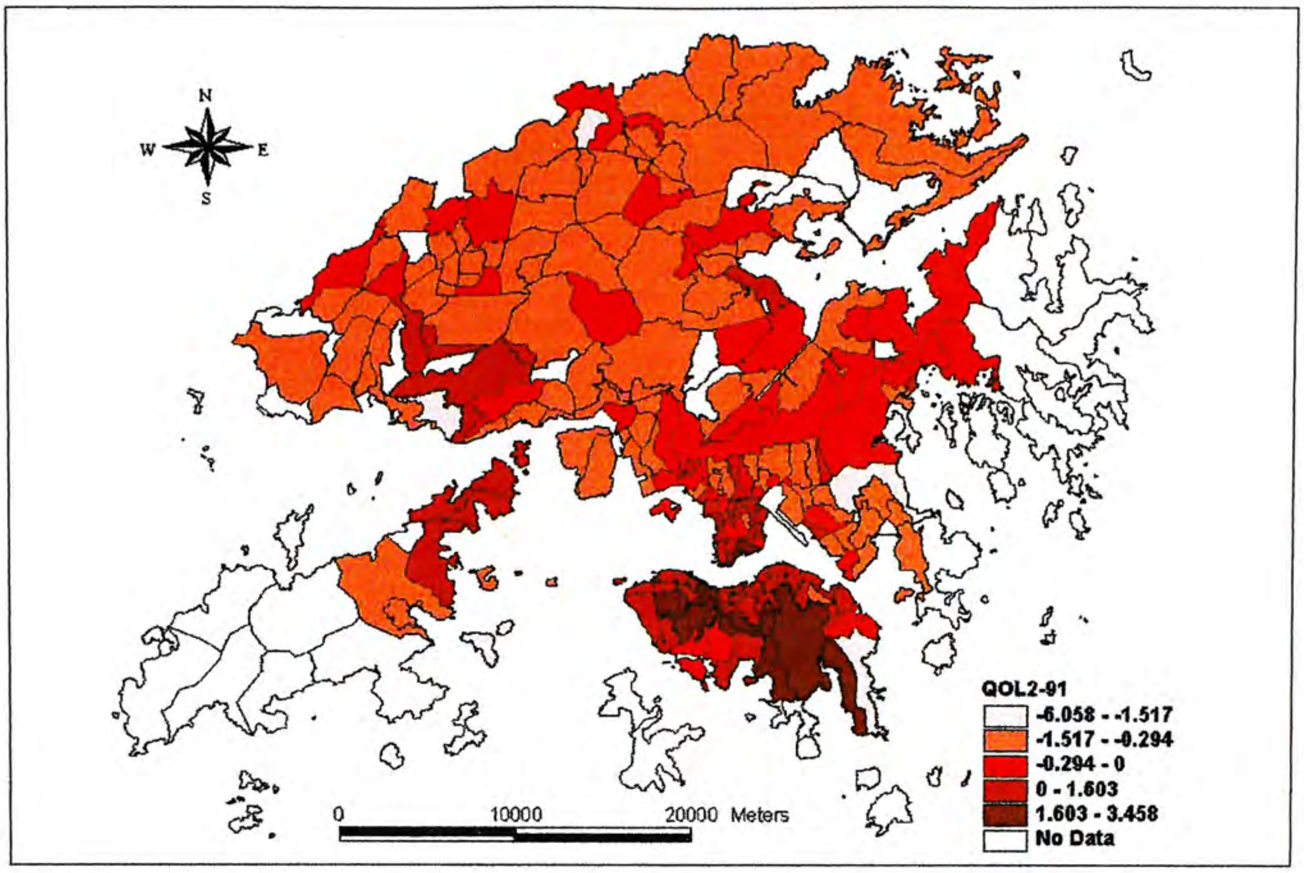


Figure 6.4 QOL2-91 (Purchasing power in 1991)

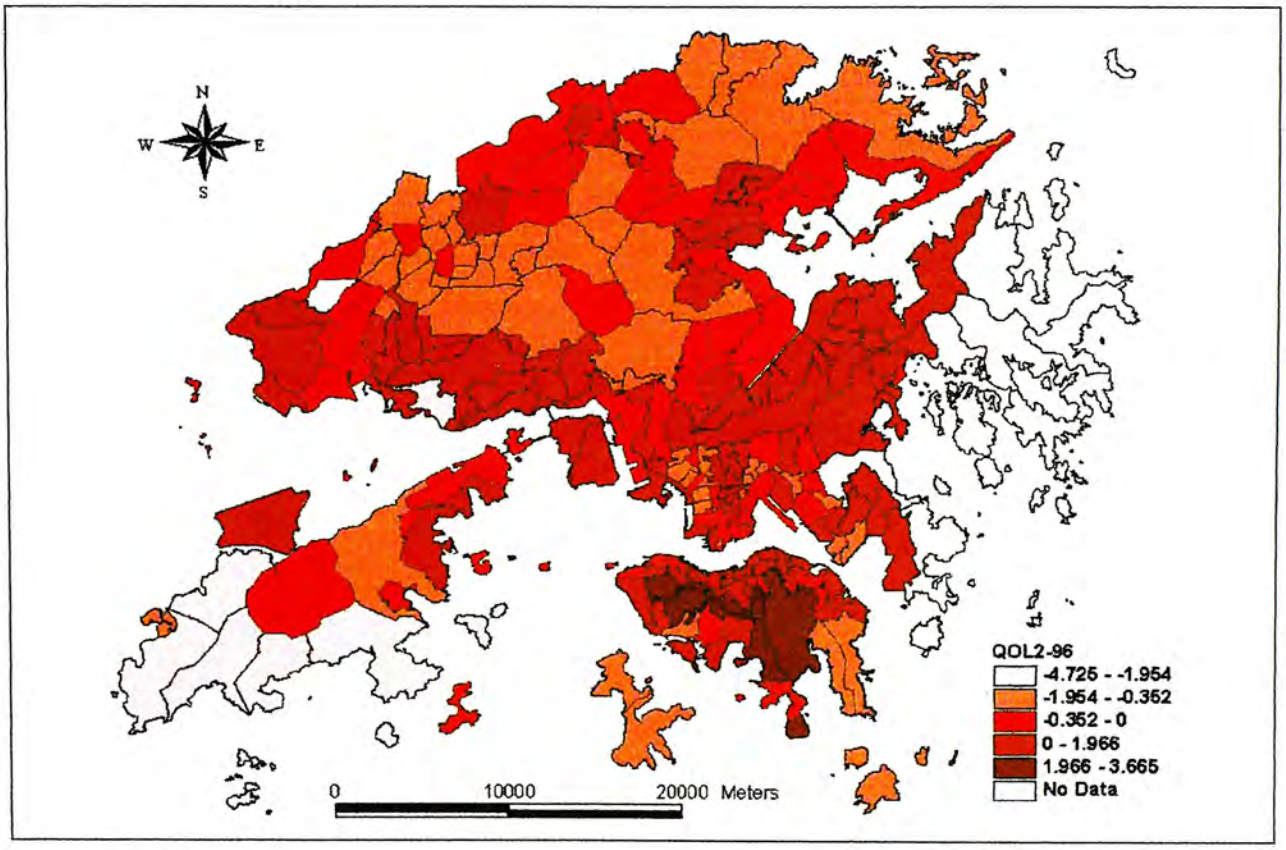


Figure 6.5 QOL2-96 (Purchasing power in 1996)

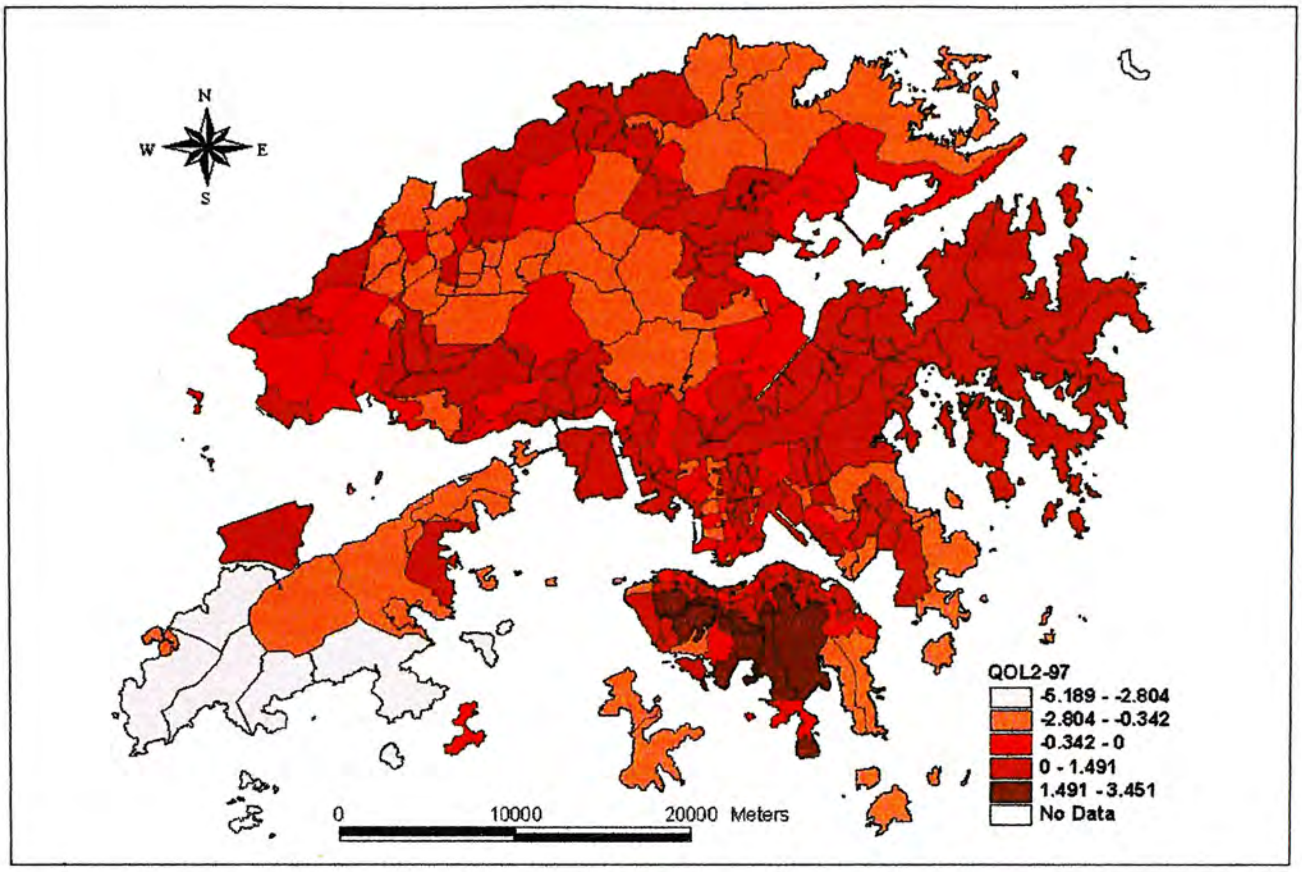


Figure 6.6 QOL2-97 (Purchasing power in 1997)

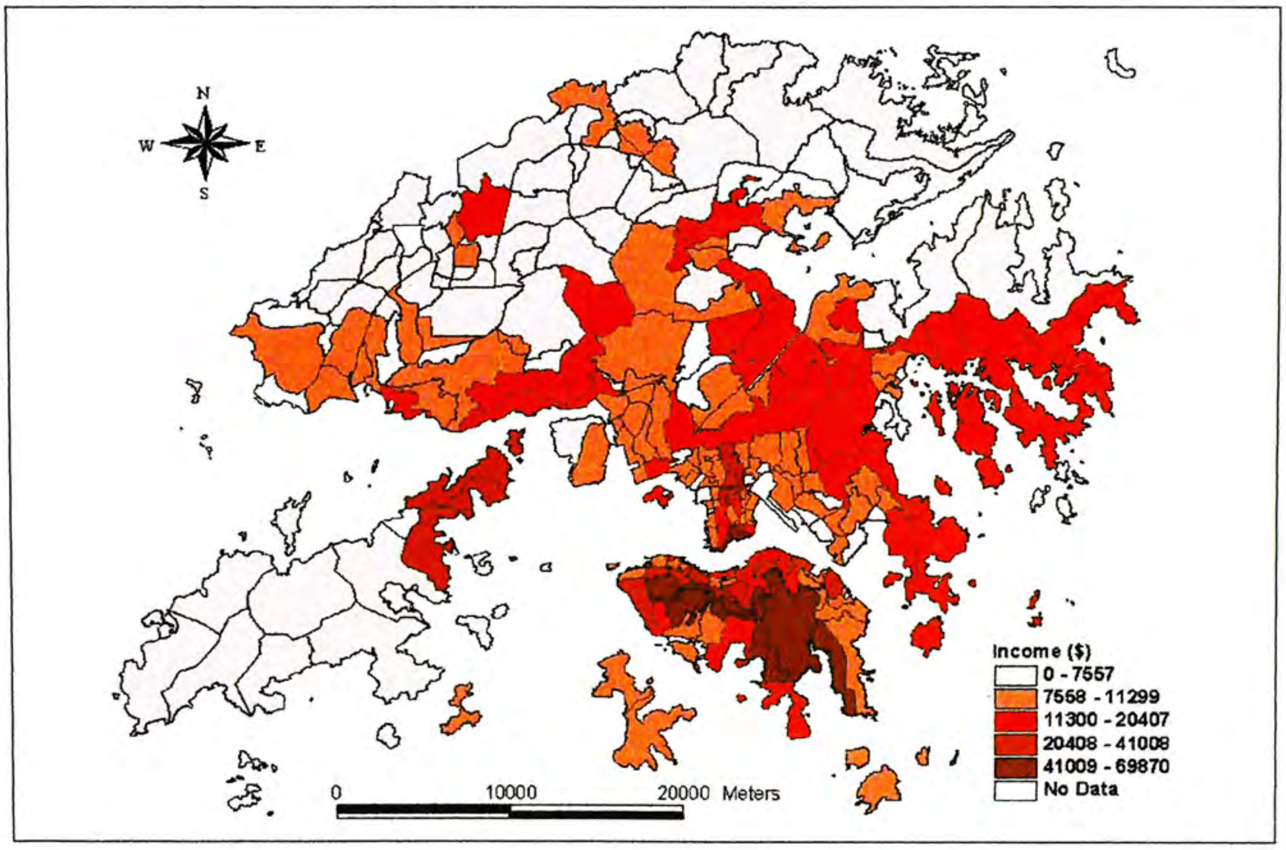


Figure 6.7 Income level in 1991

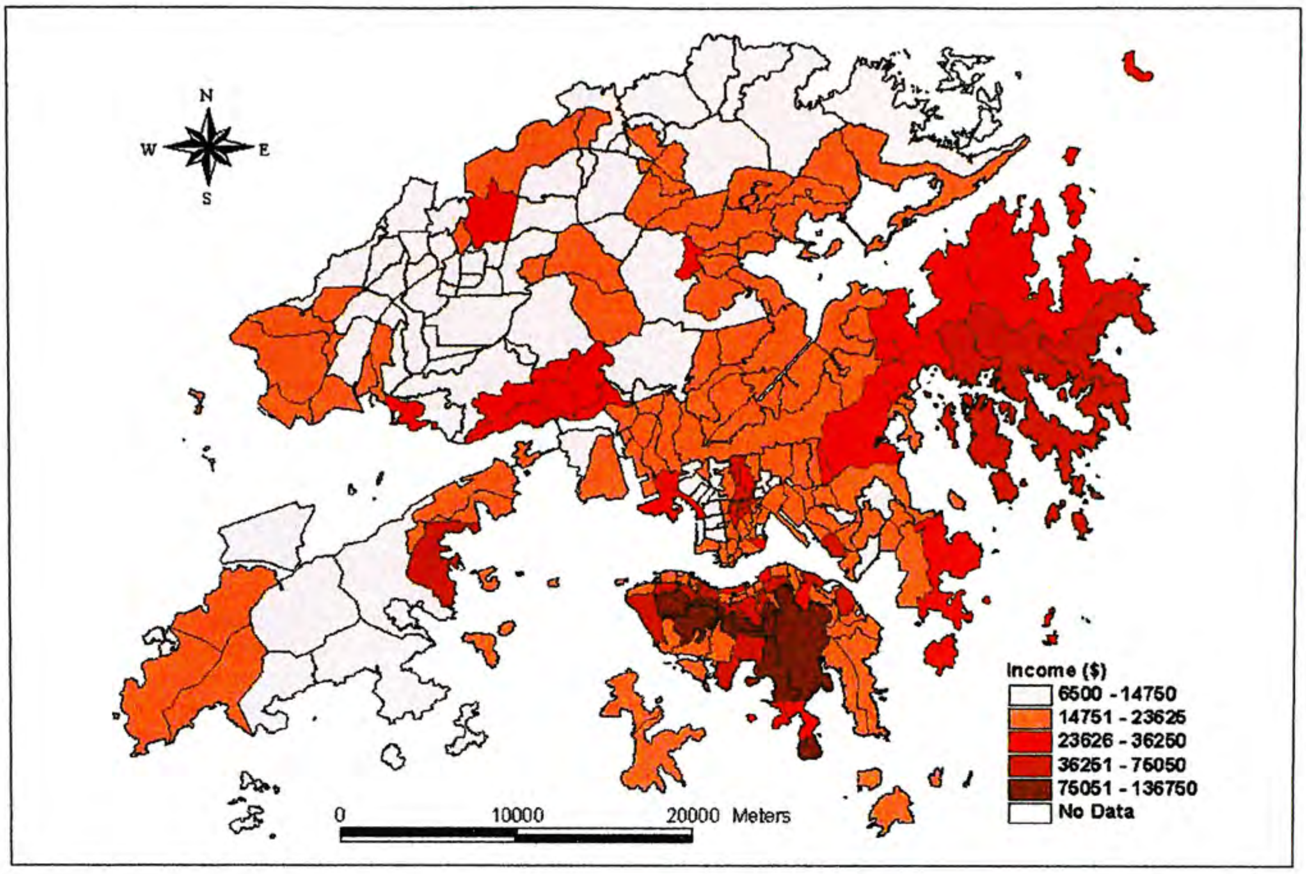


Figure 6.8 Income Level in 1996

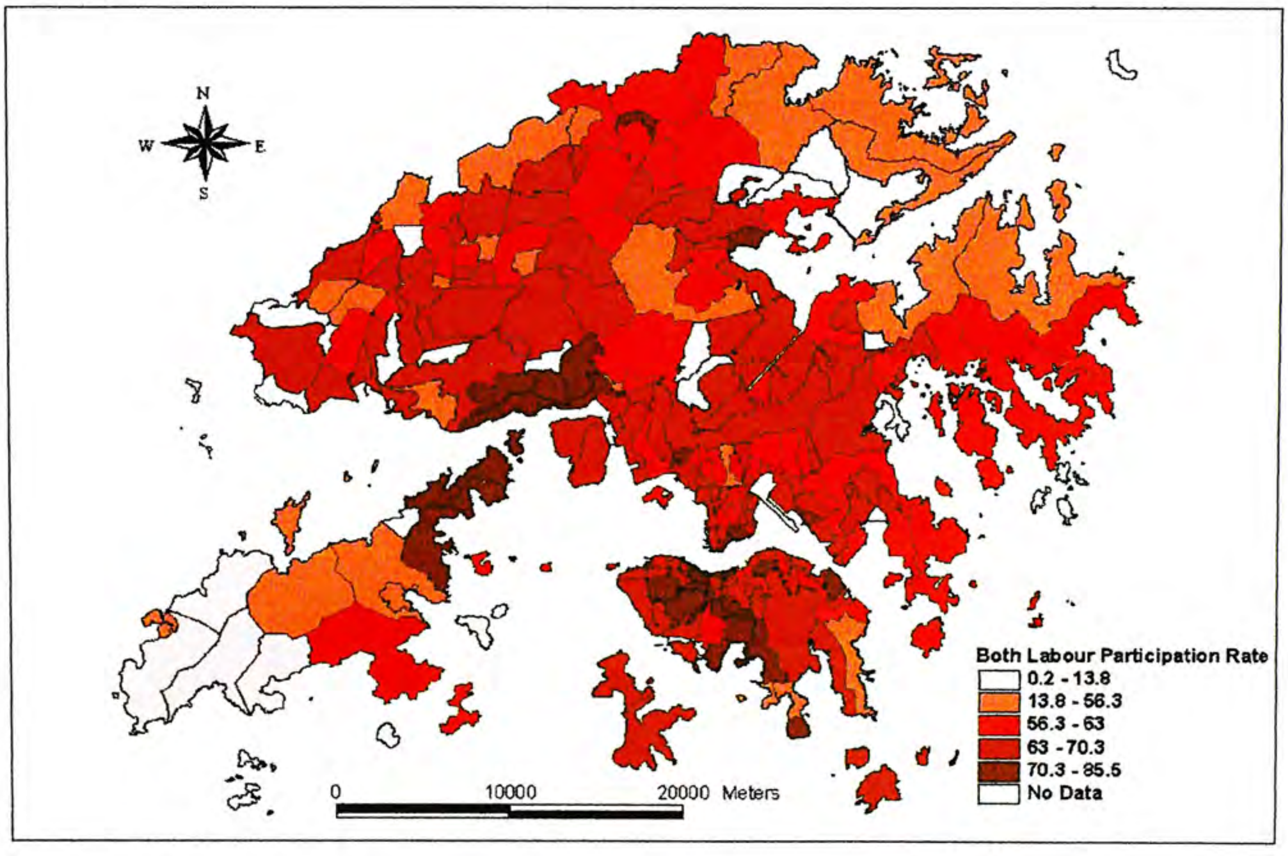


Figure 6.9 Both labour participation rate in 1991

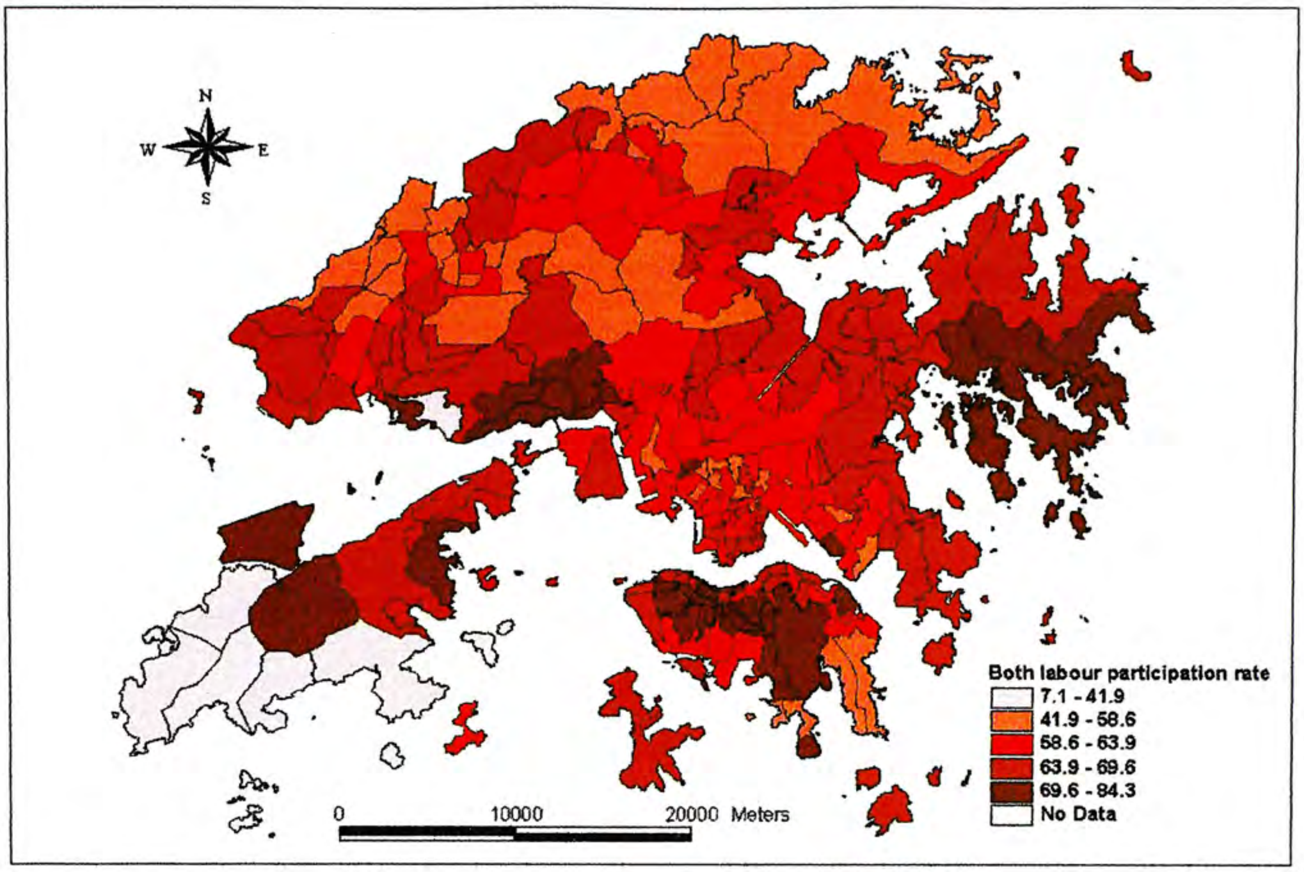


Figure 6.10 Both labour participation rate in 1996

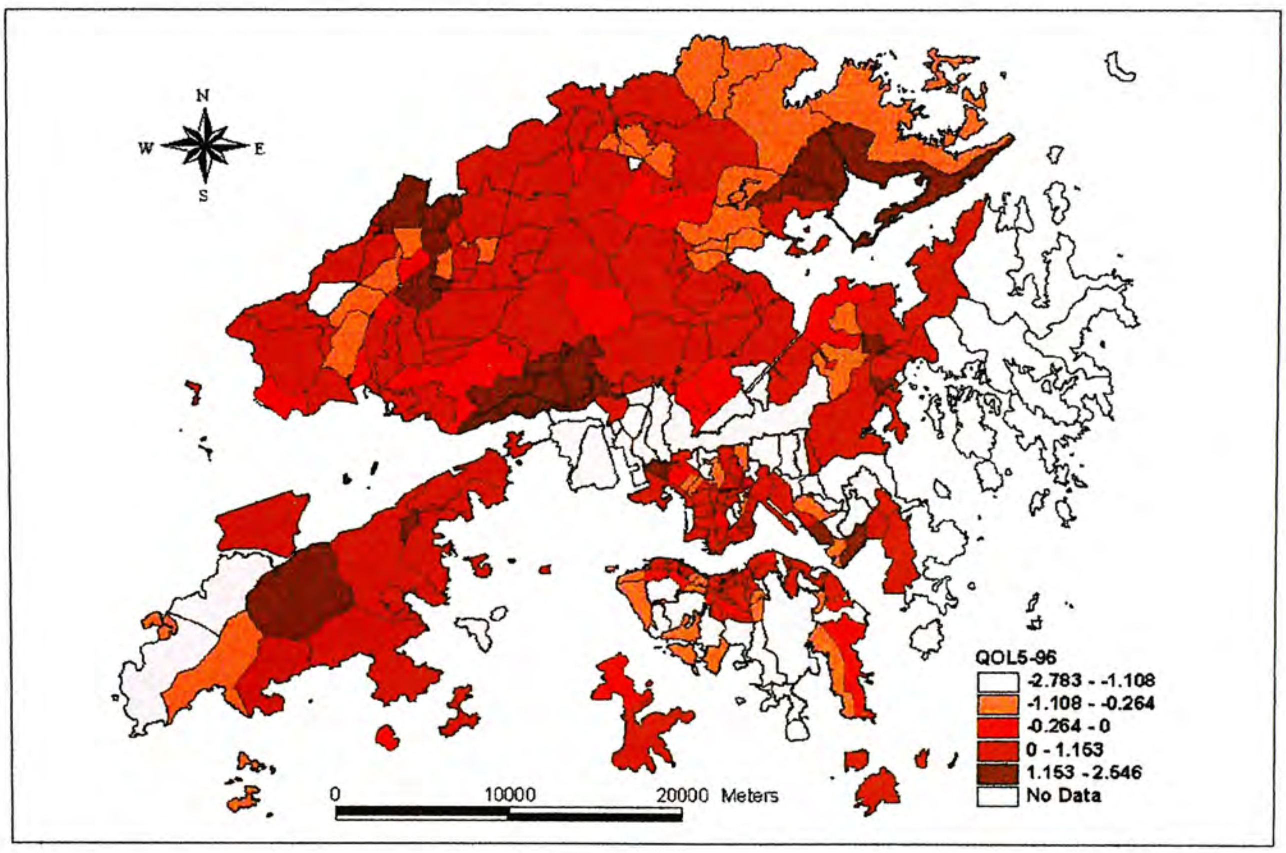


Figure 6.11 QOL5-96 (Home ownership in 1996)

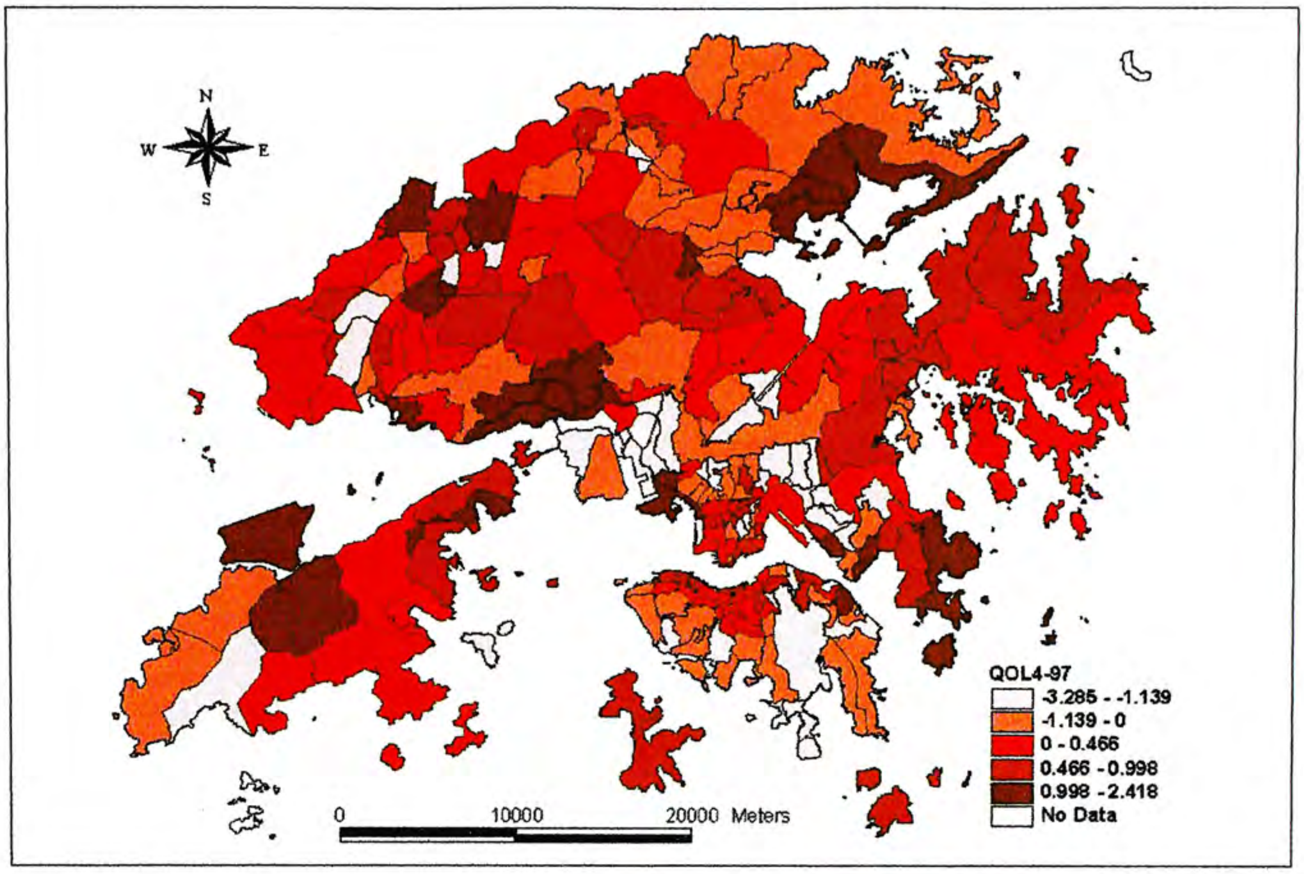


Figure 6.12 QOL4-97 (Home ownership in 1997)

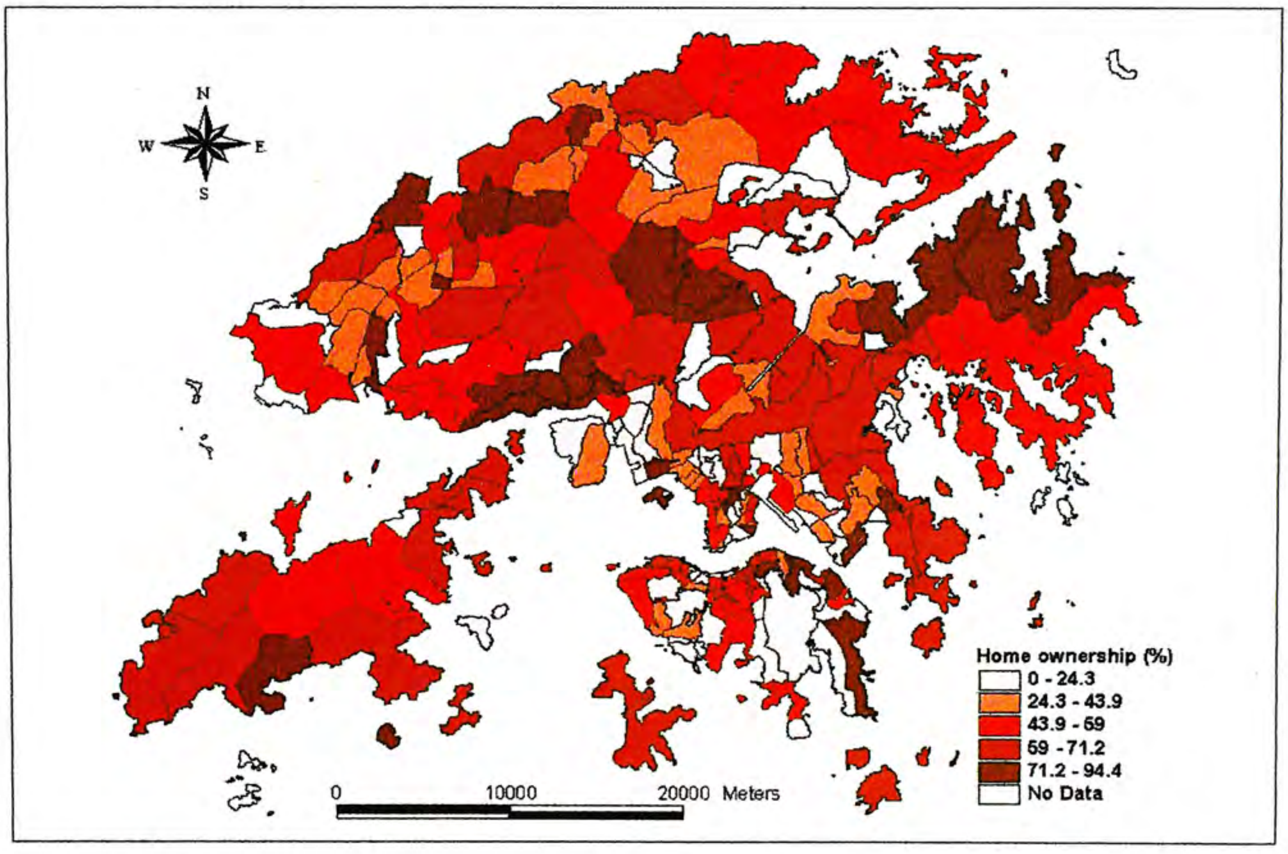


Figure 6.13 Percentage of home ownership in 1991

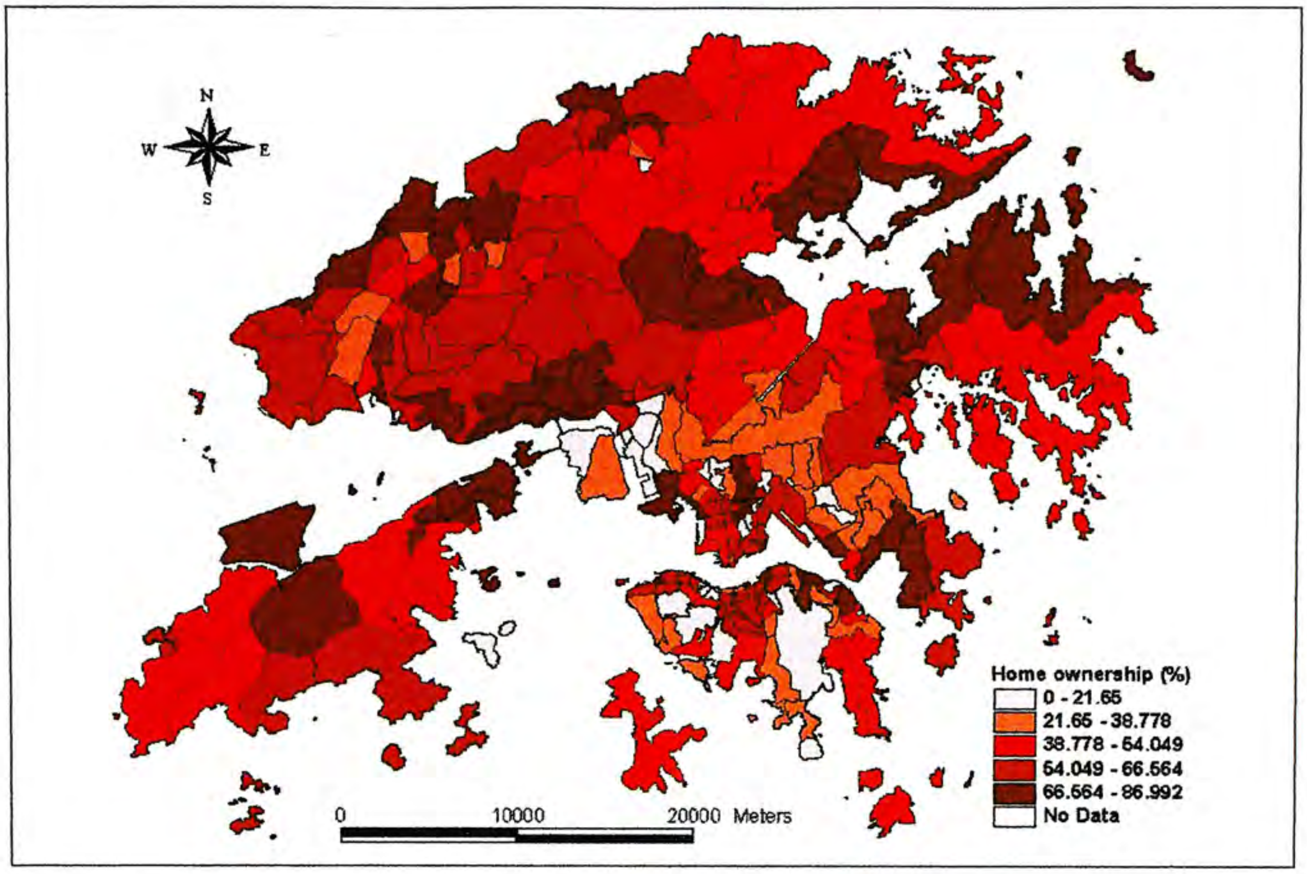


Figure 6.14. Percentage of home ownership in 1996

houses in urban areas. The highest factor score values in 1996 and 1997 were found in Tin Shui Wai, Hong Lok Yuen, areas near Plover Cove reservoir, Sham Tseng, Kowloon Tong, Tung Chung, Laguna City, Heng Fa Chuen and Tai Koo Shing where were so-called residential zone for high-income or upper-middle class group. Since the socioeconomic data for 1996 and 1997 data sets were actually the same one, the pattern for QOL4-97 and QOL5-96 were similar.

It is found that both the 1997 SPOT and the 1996 TM data yielded similar result when integrated with 1996 by-census data. They both generated the QOL indicators like degree of vegetation vigor, purchasing power and home ownership. It implied that both TM and SPOT data can be used for QOL indicators generation.

6.4 Temporal Variation of Quality of Life

Table 6.4 showed the principal components extracted from the 1991-7 data set so as to derive temporal variations of QOL. Six components were derived and explained 67% of total variance. Other than the variables BOTH_LAB, INCOME, NDVIM, NDVID and POP_DEN used in the above PCA, other variables were included in the analysis in the 1991-7 data set. They were F_LABOUR, XS2M, ELEM, WORK3, A0-14, HH4, SAVIM and URBAND.

For XS2M and SAVIM, they had some implications for QOL. Considering the equation for calculating NDVI, the higher the visible red band, the lower the NDVI yielded. SAVIM was another vegetation index showing the vegetation vigor. Thus XS2M and SAVIM show negative and positive relation to QOL respectively.

For F_LABOUR, ELEM, WORK3, A0-14, HH4 and URBAND, they showed the socioeconomic and biophysical status. Although they had no direct influence to QOL, they were put into PCA so as to find out if their interaction with other variables could generate QOL indicators.

Component 1 (QOL1-9197) showed that there was an increase in the purchasing power evidenced by the increase in income level of $10039.9 from 1991 to 1996 in average as extracted from the census reports. Moreover, increase in F_LABOUR and BOTH_LAB implied that more members in a household were engaged in working sectors and would thus increase the income level of a family. This component represented increase in purchasing power. As aforementioned, increase in purchasing power had positive effect on QOL. QOL1-9197 thus acted as a QOL

Table 6.4 Principal components analysis for the 1991-7 data set

	Component						Communal-Ities
	1	2	3	4	5	6	
BOTH_LAB	**0.89**	0.01	0.09	-0.09	-0.05	0.00	0.81
F_LABOUR	**0.87**	-0.06	0.06	-0.07	-0.04	0.02	0.77
INCOME	**0.59**	0.37	-0.19	0.16	0.12	-0.07	0.57
NDVIM	-0.03	**-0.86**	-0.08	0.19	-0.21	0.03	0.83
XS2M	0.06	**0.74**	-0.21	0.10	-0.37	0.04	0.74
ELEM	-0.10	0.09	**-0.79**	0.02	0.07	0.02	0.65
WORK3	-0.05	-0.17	**0.64**	0.16	0.37	-0.21	0.64
NDVID	-0.06	0.21	**0.56**	0.05	-0.24	0.35	0.54
A0_14	-0.02	0.01	0.11	**0.79**	-0.10	0.06	0.64
HH4	-0.10	-0.04	-0.08	**0.71**	0.05	0.04	0.52
SAVIM	0.18	-0.07	0.19	**0.46**	0.28	-0.30	0.44
POP_DEN	-0.03	0.03	-0.07	0.01	**0.85**	0.15	0.75
URBAND	0.02	-0.04	0.01	0.05	0.16	**0.88**	0.81
Eigenvalue	1.96	1.52	1.49	1.44	1.24	1.07	
% of Variance	15.06	11.69	11.49	11.06	9.52	8.19	

indicator. TPU showing increased purchasing power had a higher QOL and tended to fetch a higher factor score.

Component 2 (QOL2-9197) was interpreted as decrease in vegetation vigor because of its high negative loading on NDVIM and positive loading on XS2M (the visible red band). A decrease of NDVIM was mainly related to the increase in urban development between 1991 and 1997. For example, the development of the new airport had lowered the NDVIM in northern Lantau. Furthermore, the 1997 SPOT was acquired in January but the 1991 SPOT was acquired in December, approaching to mid-winter in Hong Kong, the grass may turn yellow and leaves of some deciduous trees may fall that resulted in a decrease of the biomass content. Considering the equations for calculating NDVI, the higher the visible red reflectance, the lower the NDVI resulted. It is a QOL indicator representing the decrease in greenery. Thus, a higher factor score in the TPU showed a decrease in vegetation vigor with lowered QOL.

Component 3 had a strong positive loading on WORK3 but negative factor score on ELEM. The former showed economic restructuring form secondary sector to tertiary sector industry. The latter implied that fewer Hong Kong citizens had low educational attainment of elementary level. In other words, people were better educated. From the census reports, there were 9.65% and 4.03% increases in proportion of secondary educated and tertiary educated population respectively. Although education attainment could show the temporal change of QOL (Foo, 2000), economic restructuring did not have any direct implication on QOL, integration of these two variables cannot be used to analyze QOL.

Component 4 showed an increase in number of children and more families having four members as well as an increase in vegetation vigor. This was evidenced by the positive strong factor score on A0-14, HH4 and SAVIM. Due to the influx of young immigrants, the household size increased. Of the new arrivals recorded, the children aged 14 or below had the highest percentage in 1996 and the population of this age group had increased by 32.6% from 1989 to 1996 (Siu, 1998). However, the implications on QOL awee not obvious and thus cannot be regarded as QOL indicator in this stage. It was because the combination of young children, medium household size did not have implication on QOL. Although SAVIM had positive relation of QOL, integration of all these variables cannot show any changes in QOL.

Component 5 (QOL5-9197) had a strong positive loading on POP_DEN. As explained above, population density had adverse implication on QOL. Therefore, increase in POP_DEN lowers QOL and this variable was thus employed as a negative QOL indicator in this study. TPU with an increase in population density resulted in a lowered QOL and tended to generate a higher factor score.

Component 6 shows that there was an increase in diversity of urban land as shown by the positive heavy loading on URBAND. Since there were as many as 815 388 m^2 of land areas under urban renewal and redevelopment taking place in old districts in 1997 (Planning and Land Bureau, 1999), the environment of these districts like Mongkok and Wanchai were changed. This probably resulted in an increase in diversity of urban land. However, it just showed the changes in biophysical environment and did not have contribution to QOL. Therefore, this component was not used as QOL indicator.

Figures 6.15, 6.16 and 6.17 represented the spatial pattern of changes in the biophysical environment for QOL1-9197, QOL2-9197 and QOL5-9197 respectively. It was found that only component 3 and component 4 had loadings on both changes in biophysical variables and socioeconomic variables. However, other components were still adopted as QOL indicators representing either the biophysical or socioeconomic environment.

QOL1-9197 was interpreted as increase in purchasing power as the positive factor score indicated an increase in purchasing power and vice versa. It was noted that Sham Tseng, Mid-Level, Sai Kung, Discovery Bay, Stanley, Fairview Park, Hong Lok Yuen and Kowloon Tong experienced an increase in purchasing power, whilst districts like Mongkok, Yau Ma Tei, Tsing Yi, Tuen Mun, Shatin and Fanling-Sheung

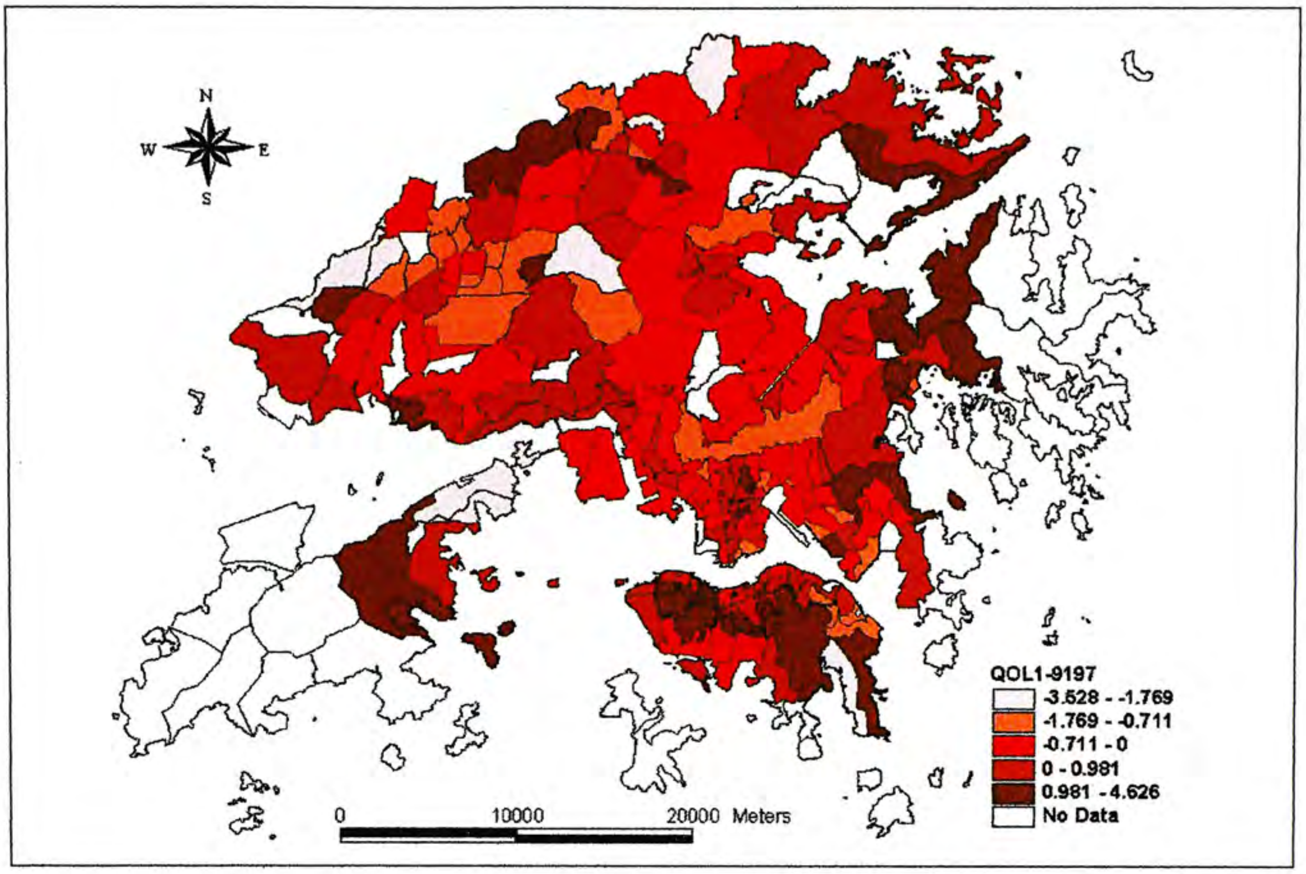


Figure 6.15 QOL1-9197 (Increase in purchasing power)

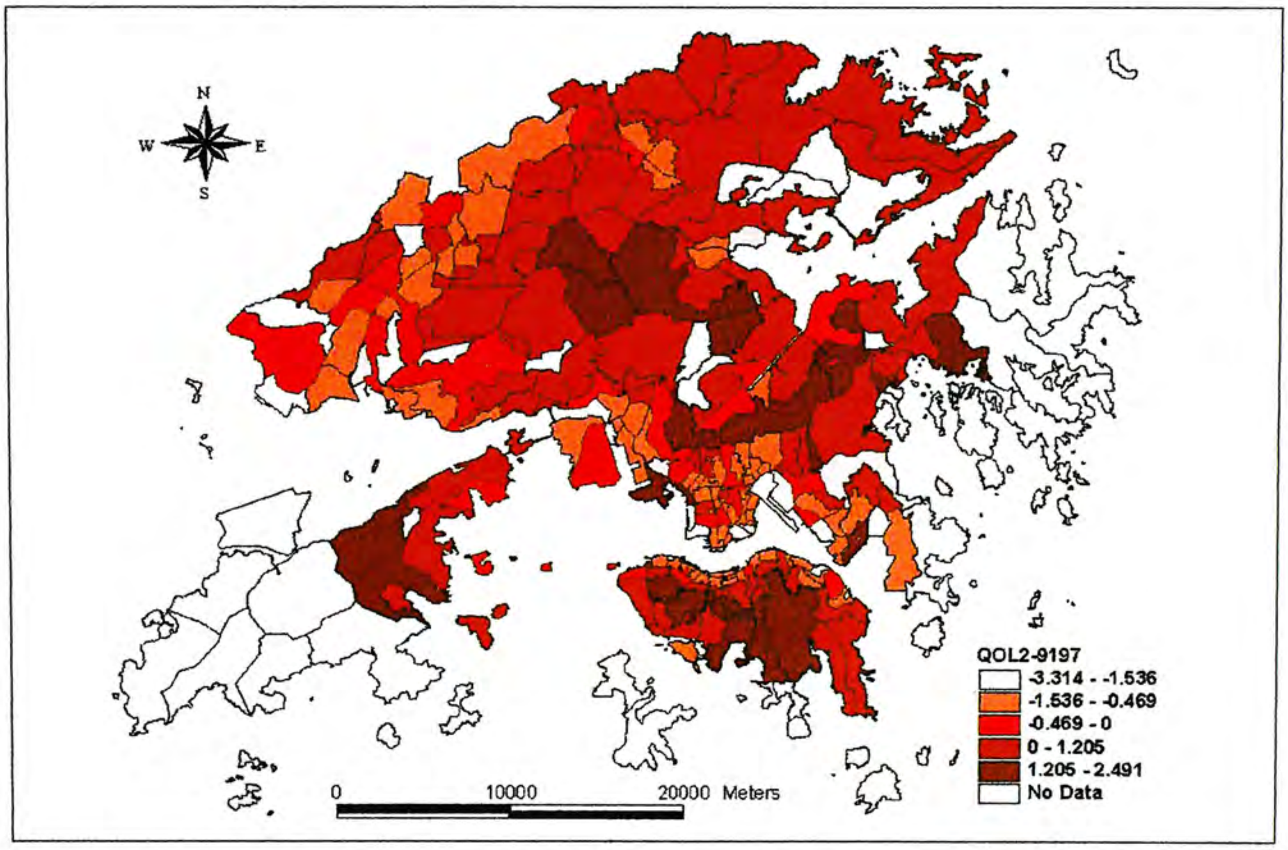


Figure 6.16 QOL2-9197 (Decrease in vegetation vigor)

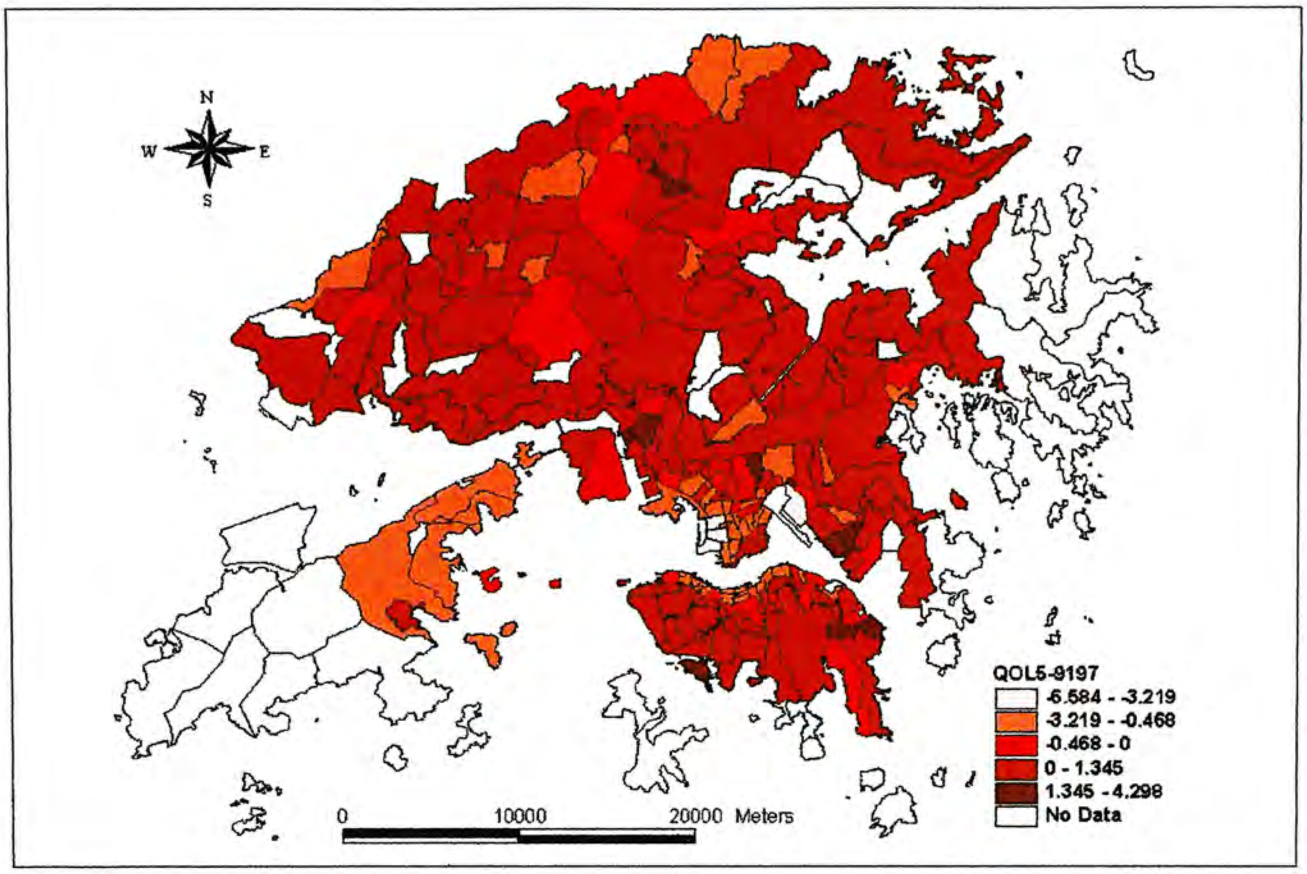


Figure 6.17 QOL5-9197 (Increase in population density)

Shui experienced a reduction. It indicated that there was an increase in income polarization, as the purchasing power tended to increase in areas where high-income group were found and decrease in areas where low-income group were concentrated. This argument can be supported by the income inequality (as measured by the Gini coefficient) identified in the study on Sustainable Development for the 21st Century in Hong Kong which the income inequality had increased by 14.3% between 1986 and 1996, with the Gini coefficient increased from 45.3 to 51.8 (Planning Department, 2000).

QOL2-9197 was interpreted as decrease in vegetation vigor as the higher the factor score the more the decrease in vegetation vigor. In other words, it showed a decrease in QOL. Areas like northern Lantau and Stonecutter Island experienced a decrease in vegetation vigor which may be due to development of the new airport and West Kowloon Reclamation Projects during the mid-1990s. Most areas in country parks experienced a decrease in vegetation cover. This may be due to the different acquisition dates of two SPOT images. The 1991 SPOT image was acquired in December while the 1997 SPOT image was acquired in January. As January is mid-winter time in Hong Kong, lower vegetation vigor and hence smaller NDVI values were expected. However, there was an increase in vegetation vigor in Mai Po, part of Taipo, Lai Chi Kok and Kwun Tong which may be resulted from an increase in mangrove and the awareness and implementation of urban greenery.

QOL5-9197 was interpreted as increase in population density which indicated decrease in QOL as the degree of crowdedness increases. Most area like the Mid-Level, Shatin, Yuen Long, Fanling and Tuen Mun experienced an increase in population density. However, some areas like Sham Shui Po, Yau Ma Tei, Lai Chi Kok and Wanchai experienced a decrease in population density, which may be due to the new town and urban renewal policy that population were dispersed and became less concentrated in metropolitan areas.

6.5 Summary and Discussion

Not all principal components extracted were QOL indicators, only the following QOL indicators can be extracted. QOL1-91, QOL1-96 and QOL1-97 showed vegetation vigor. QOL2-91, QOL2-96 and QOL3-97 represented purchasing power. QOL4-97 and QOL5-96 showed proportion of home ownership. Moreover, QOL1-9197, QOL2-9197 and QOL5-9197 were interpreted as increase in purchasing power, vegetation cover and population density respectively. All of these indicators were mainly related to purchasing power, vegetation vigor, population density and proportion of home ownership.

Comparison of objective QOL indicators among 1991, 1996 and 1997 data sets in terms of QOL1 showed that there was a better QOL in rural area as more green space and vegetation cover are preserved in the countryside. In metropolitan areas, districts such as the Mid-level, Kowloon Tong, the Southern District and Happy Valley experienced a relative higher QOL1 factor score value than other urban areas as they were low density residential zone of high-income and upper-middle class groups. New towns also had a higher QOL1 factor score value than metropolitan areas as these new towns were well designed with more green space.

QOL2 presented the QOL in terms of purchasing power which had a completely different picture from QOL1. Urban areas particularly the Mid-level and the Southern district had a better QOL. QOL5-96 and QOL4-97 represent QOL in terms of home ownership, it was found that home ownership was high in Tin Shui Wai, Hong Lok Yuen, areas near Plover Cove reservoir, Sham Tseng, Kowloon Tong, Laguna City, Heng Fa Chuen and Tai Koo Shing which resulted in a higher QOL. However, these QOL indicators were not in conflict with each other. It depended on which aspect the focus was.

It was found that the change of QOL was related to the new town development in Hong Kong. As seen from the figures, the major changes in QOL, no matter increase or decrease, were mainly found near new towns like Shatin, Yuen Long and Tin Shui Wai. This was reasonable to conclude that QOL is related to governmental policy on land development and conservation. Development resulted in QOL degradation whilst conservation kept QOL constant.

From Figures 6.1, 6.2 and 6.3, it was discovered that areas within country park boundary and areas in hills had highest quality of life in Hong Kong. However, it was doubtful that if any one was willing to reside in the hills and can reside in country parks so as to attain a higher quality of life. It was illegal to live in country parks without permission and people were unwilling to live in the hills. In fact, environments in the hilly areas, no matter hillside or hilltop, were harsh for living in terms of infrastructure provided and temperature fluctuation etc. However, this study used only six to seven variables for studying quality of life and the results showed the interaction among these variables only. Other parameters such as ease to transportation, accessibility and altitude may have an influencing power in QOL but had not been included in the study. Areas with highest vegetation cover and low population density, i.e. QOL1, was able to reveal a partial view on the quality of life in Hong Kong.

The 1996 TM and 1997 SPOT data generated the same QOL indicators with similar spatial pattern which indicated that both TM and SPOT data can be used in QOL indicators generation.

In conclusion, it was worthy to say that the data may account for part of the problem. It was believed that a more detailed result could be drawn if more detailed data can be obtained. Moreover, it was found that apart from integration of the biophysical and socioeconomic data, either biophysical or socioeconomic data alone can still be used to extract variables as QOL indicators.

CHAPTER SEVEN CONCLUSION

This research attempts to examine the relationship between spectral indices and socioeconomic factors as well as to derive an integrative measure for quality of life assessment in Hong Kong. Improving the quality of life is an important factor to maintain economic success of Hong Kong that foster Hong Kong to become the World City. Quality of Life study can provide the past and current condition that may assist resource allocation and policy formulation. It is noted that QOL is composed of the biophysical and socioeconomic variables. Integration of the two data sets can provide a comprehensive picture of quality of life.

7.1 Summary of Findings

In this study, there are two different sources of data. Firstly, biophysical data is extracted by interpreting satellite imageries. Two SPOT and one Landsat TM images are used. Biophysical variables extracted from these satellite images represent the situation in 1991, 1996 and 1997. Secondly, socioeconomic data are extracted from the 1991 census and 1996 by-census reports. Hence, three data sets are used for analysis, i.e. the 1991 census data and the 1991 SPOT image, the 1996 by-census data and the 1997 SPOT image and the 1996 by-census data and the 1996 TM image.

To derive the relationship between socioeconomic and biophysical variables, stepwise multiple linear regression models are established. The quality of life indicators are then derived by principal component analysis using the biophysical and socioeconomic variables. These QOL indicators are then mapped in TPU level so that the spatial and temporal variation of QOL in Hong Kong can be assessed.

7.1.1 Inter-relationship between socioeconomic and biophysical variables

There are two methods of regression modeling used to examine the inter-relationship between socioeconomic and biophysical variables. One uses raw or principal component of biophysical variable as dependent variable and socioeconomic variables as independent variables. The other one uses raw or principal component of socioeconomic variable as dependent variable and biophysical variables as independent variables.

Modeling results show that the 1991 data set has a better integration result as more models are identified with coefficient of determination (R^2) value greater than 0.4 among the three data sets. Among the models developed, it is noted that population density and degree of crowdedness are negatively related to vegetation indices, vegetated area, greenness and near-infrared band. However, a positive relation is found between urban area and population density. Both are measures for degree of crowdedness that yields a R^2 greater than 0.4. It is also noted that the TM and SPOT data yield similar results.

7.1.2 Quality of Life Indicators

Principal component analysis is used to identify QOL indicators by reducing "selected" socioeconomic and biophysical variables into uncorrelated components. The "selected" socioeconomic and biophysical variable refers to the representative variable of every principal component which is interpreted through analyzing the raw data. Selected socioeconomic variables are INCOME, BOTH_LAB, HH5, A15-39, POP_DEN and OWNER while selected biophysical data are NDVIM, NDVID, BAREM, SOILM, WATERM and TEMPERM.

Analysis results show that only one QOL indicator includes both socioeconomic and biophysical variables in its factor loading. It consists of population density and vegetation vigor. Other indicators present either socioeconomic or biophysical environmental conditions. These QOL indicators are vegetation vigor, purchasing power and home ownership.

Mapping the QOL1, it is found that QOL is better in rural areas, particularly in areas like Tai Mo Shan, Sai Kung and NW coastal areas. On the other hand, poor QOL is noted in urban areas except Kowloon Tong, Pok Fu Lam, Mid-Level, the Southern District, Tai Koo Shing and Happy Valley where there is a lower factor score than rural areas but a higher score than other urban areas.

Representing purchasing power, QOL2 is high in urban areas particularly the Mid-level and the Southern District where high income groups resided. For home ownership, i.e. QOL3, it is noted that QOL in rural areas is better than in urban areas in both 1997 and 1996. For these two indicators, the higher the factor score value, the better the QOL is. The QOL indicators generated from SPOT and TM images yields similar results.

For the temporal variations, it is noted that there is an increase in purchasing power (QOL-9197) particularly in Sham Tseng, Mid-Level, Sai Kung, Discovery Bay, Stanley, Fairview Park, Hong Lok Yuen and Kowloon Tong. However, there is also a reduction in purchasing power in districts like Mongkok, Yau Ma Tei, Tsing Yi, Tuen Mun, Shatin and Fanling-Sheung Shui.

QOL2-9197 presents that most areas in country parks have experienced a decrease in vegetation vigor but there is an increase in vegetation vigor in Mai Po, part of Taipo, Lai Chi Kok, Kwun Tong.

QOL5-9197 is interpreted as increase in population density which indicates decrease in QOL as the degree of crowdedness increases. Most area like the Mid-Level, Shatin, Yuen Long, Fanling and Tuen Mun experience an increase in population density. However, some areas like Sham Shui Po, Yau Ma Tei, Lai Chi Kok and Wanchai experience a decrease in population density which may be due to new town development and urban renewal that population become less concentrated in the metropolitan areas.

Changes in QOL are related to new town development in Hong Kong. Areas with major QOL changes are found near new towns like Shatin, Yuen Long and Tin Shui Wai. This is reasonable to conclude that the QOL is related to governmental policy on land development and conservation. Development results in QOL degradation whilst conservation keeps QOL constant.

Regression modeling shows that only population density and vegetation vigor are strongly and significantly interrelated with each other. Quality of life indicators derived show that only QOL1 include both biophysical and socioeconomic variables, that is, the vegetation vigor and population density. Other indices reflect either socioeconomic or biophysical condition but not both. Integration of both biophysical and socioeconomic data can develop a QOL index. However, it is found that using either socioeconomic or biophysical data alone can also reflect other aspects of QOL.

7.2 Limitations of the Study

Although QOL models are developed successfully, however, this study experiences certain limitations.

As mentioned in Chapter Three, the smallest areal unit for census and by-census data is provided at TPU level. Thus, all data, including census data and satellite image data, can only be analyzed at TPU level. Each TPU is assumed to be a homogeneous area. People who live in anywhere of a particular TPU experience the same level of QOL. However, this is not always true especially in those TPU characterized with highly spatial variation in development. Taking the TPU in Tseung Kwan O as an example, TPU consists of heterogeneous landuse and land cover type, like hilly and vegetated areas, open areas and urban areas. QOL in different parts of the TPU is different. This suggests that a more detailed level of analysis is needed.

On the other hand, satellite images are not acquired on anniversary dates. The 1991 SPOT was acquired on 21st December, 1991, the 1996 TM was acquired on 3rd March, 1996 and the 1997 SPOT was acquired on 29th January, 1997. Such characteristics create some problems to this study. Firstly, the data extracted from the images represent a point in time only. However, data are used to infer an annual condition and are integrated with socioeconomic data in this study. This integration method bears error. Moreover, the most acute problem is the changes in vegetation cover in different periods. December and January are the winter period when the vegetation cover is assumed to be low. March, however, is spring when the vegetation, in particular grass starts growing. Therefore, only SPOT data are used for studying the temporal changes to minimize this error.

Socioeconomic data was acquired from the 1991 census and 1996 by-census data. The data collection methods for the two years census and by-census data are different. The 1991 census data was collected using *de facto* enumeration approach, while the 1996 by-census data adopted the *de jure* enumeration approach. Different data collection approach may slightly affect the census data result. However, these data still represent the socioeconomic nature of the population in each TPU and can still be comparable.

In developing QOL indicators, only three QOL variables for SPOT and TM data respectively are selected for study, these variables only represent part of the QOL picture. Other socioeconomic data like crime rate, infrastructure and transportation facilities may also have an influence on quality of life. However, these data are not available at TPU level and not included in the study. In other words, this study only reveals part of QOL and cannot represent a holistic picture of QOL.

7.3 Recommendations for Further Studies

This study is based on the TPU level which is not detailed enough particularly in areas with large variations. Alternatively, it is suggested to study QOL in Hong Kong at a raster base which socioeconomic data should be fitted in every pixel with the aid of a higher resolution satellite image or aerial photos. This study is conducted on a vector base, data model under which areas (pixels) within a TPU is assumed to be homogeneous. Using a raster based data model, data will be studied in pixel level which is more detailed and can better reveal the QOL situation. Socioeconomic data should be fitted into each pixel and integrated with pixel based biophysical data for QOL analysis. However, it will lead to a problem of over generalized socioeconomic data as they are originally integrated at TPU level. To minimize this problem, it involves estimating the socioeconomic data into more detailed pixel level or alternatively, a block level socioeconomic data can be introduced.

The IKONOS image with 1m or 4m resolution is an alternative choice for providing detailed information of the study area. The higher resolution images provide more detailed data like transportation network, distribution of urban greenery and accessibility to local amenities like libraries, city halls and schools which may affect QOL of the residents. By following the similar method of analysis, it is expected that QOL analysis will yield a finer picture. However, the cost of the image is high. It is costly to buy the images covering the entire territory of Hong Kong.

Moreover, a more detailed level of QOL study should be implemented in Hong Kong based on conducting interviews or questionnaires. This qualitative analysis helps to find out exactly how the citizens feel about different factors of QOL. Interviews can provide one's satisfactory on different QOL aspects using likert scale questions. Relationship between one's satisfactory level and census data help to generalize a detailed regional QOL. However, large human resources and high time cost may be involved in conducting these interviews and questionnaires.

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APPENDIX A GROUND CONTROL POINTS ERRORS

Table A1 Root Mean Square Error (RMSE) of the 46 Ground Control Points (GCPs) of 1991 SPOT and ordered from worse to best residuals

GCP	Georeferenced GCPs (meter)		Uncorrected GCPs (pixel)		Residual (pixel)		RMSE
No.	X	Y	X	Y	X	Y	
1	830031.9	815106.9	1440.4	1908.1	-0.3	-1.18	1.22
2	838763.8	820336.3	1830.4	1582.4	0.5	1.09	1.2
3	822985.6	833890.6	943.4	1037.6	0.86	-0.83	1.2
4	836856.9	814686.9	1780.6	1874.4	-0.63	-0.9	1.1
5	835244.4	810816.9	1733.6	2079.9	0.72	0.74	1.04
6	834439.1	821194.1	1608.4	1573.9	-0.98	0.29	1.03
7	838972.8	827915.9	1780.1	1205.1	0.84	-0.52	0.99
8	822221.6	820205.9	1013.6	1719.4	-0.51	-0.73	0.89
9	843683.8	814486.3	2120.1	1829.6	-0.12	-0.81	0.82
10	840440.9	829847.2	1835.8	1098.3	-0.56	-0.37	0.67
11	820735.6	826045.6	893.8	1444.3	-0.3	0.54	0.62
12	833249.4	826634.4	1506.6	1314.1	-0.31	-0.52	0.61
13	815369.4	825753.1	632.1	1500.6	0.44	-0.38	0.58
14	832906.3	811673.8	1610.8	2056.1	0.36	0.45	0.58
15	831900.3	816650.9	1520.4	1818.6	-0.19	0.54	0.57
16	834441.9	820645.6	1614.1	1601.1	0.21	0.5	0.54
17	824308	825139.5	1077.4	1460.4	-0.19	0.48	0.52
18	819145.6	837363.1	725.6	898.1	0.06	0.5	0.5
19	842201.6	836494.1	1870.6	756.8	0.45	0.21	0.5
20	818295.3	813799.1	872.1	2067.4	0.28	-0.41	0.49
21	822853.4	837632.2	905.8	855	-0.43	0.18	0.47
22	837933.1	834595.6	1674.2	884.1	-0.33	-0.3	0.44
23	839746.3	813436.3	1933.9	1914.1	-0.27	0.32	0.42
24	807685.6	817004.4	322.8	1994.8	0.07	0.35	0.36
25	831111.9	821035.6	1446.4	1608.4	0.04	0.34	0.35
26	842410.7	816909.8	2038.1	1721.1	0.34	-0.04	0.34
27	837939.7	818205.3	1806.6	1692.9	0.28	-0.14	0.31
28	817579.1	819386.6	791.4	1797.9	-0.18	0.26	0.31
29	838023.8	809517.7	1880.5	2120.8	-0.25	-0.14	0.29
30	837410.9	833355.3	1658.9	949.9	0.24	0.14	0.28
31	808559.4	829413.1	266.6	1374.4	-0.13	-0.23	0.27
32	824145.3	822619.1	1089.9	1585.6	0.22	-0.04	0.22
33	849965.2	826692.3	2332	1178.2	-0.13	0.16	0.21
34	814896.9	826608.1	601.4	1462.6	-0.18	0.06	0.19
35	846351.4	826978.9	2151.4	1192.9	0.15	0.09	0.18
36	841239.7	844802.2	1756.4	354.4	-0.15	0.05	0.16
37	829624.8	823236.7	1355.4	1511.4	0.14	0.07	0.15
38	847506.9	842403.1	2084.9	422.6	-0.12	-0.09	0.15
39	840063.6	831545.5	1804.2	1017.9	0.11	0.09	0.14
40	828776.1	825896.1	1292.1	1386.9	0.1	0.03	0.1
41	845841.9	831014.4	2093.6	997.9	-0.1	0.02	0.1

42	840266.1	818252.3	1920.8	1672.1	-0.09	0	0.09
43	826736.1	822819.2	1216.1	1555.1	0.07	0.05	0.09
44	844543	824226.4	2084.1	1343.2	-0.01	0.09	0.09
45	840438.5	818429.5	1927.9	1661.9	-0.05	0	0.05
46	836684.4	816156.9	1760.9	1804.1	0.01	-0.01	0.02
				RMSE	X	Y	Overall
					0.39	0.48	0.62

Table A2 Root Mean Square Error (RMSE) of the 45 Ground Control Points (GCPs) of 1996 TM and ordered from worse to best residuals

GCP	Georeferenced GCPs(meter)		Uncorrected GCPs (pixel)		Residual (pixel)		RMSE Error
No.	X	Y	X	Y	X	Y	
1	838238.8	820186.3	1619.4	1268.1	-1.13	-0.87	1.43
2	844280.9	818899.1	1827.9	1278.4	1.32	-0.13	1.33
3	836387.2	834309.7	1482.4	813.4	-1	-0.49	1.11
4	817636.3	819976.3	943.9	1387.9	1.04	0.08	1.04
5	827828.8	820793.8	1274.9	1305.9	0.66	0.3	0.72
6	811714.1	817337.2	761.4	1506.9	-0.65	0.12	0.66
7	849483.1	844180.6	1862.6	417.4	0.65	0.16	0.66
8	830857.8	821820.3	1369.1	1255.1	0.64	-0.18	0.66
9	810575.5	809505.8	766.9	1770.1	0.01	-0.63	0.63
10	822745.9	837436.5	1017.4	784.9	0.57	-0.27	0.63
11	843546.9	835064.4	1714.9	750.4	-0.46	0.42	0.63
12	823823.8	820133.8	1145.3	1349.3	-0.58	0.2	0.61
13	840436.3	829853.8	1640.4	938.9	-0.49	0.31	0.58
14	832919.4	821106.9	1440.8	1267.8	0.48	0.15	0.51
15	829358.8	808636.3	1389.9	1698.1	-0.29	0.41	0.5
16	815650.6	826945.6	839.4	1169.4	-0.37	0.28	0.47
17	834676.3	816503.8	1523.4	1409.9	0.42	0.2	0.46
18	808941.9	829308.1	605.9	1128.1	-0.05	0.45	0.45
19	811246.3	820546.3	729.6	1403.4	0.36	-0.26	0.44
20	838788.1	827976.9	1596.6	1008.9	-0.09	-0.43	0.44
21	846392.2	826256.6	1856.3	1024.9	-0.24	0.35	0.43
22	843158.8	805493.8	1861.3	1726.3	-0.4	-0.08	0.41
23	807703	811406.1	661.7	1724	-0.29	0.26	0.39
24	811613.8	831931.3	679.6	1026.6	-0.13	-0.23	0.26
25	804030.8	812975.5	532.7	1691.7	0.1	-0.19	0.21
26	836672.7	816161.1	1590.7	1409.9	0.11	-0.18	0.21
27	828773.3	825896.1	1277.6	1132.4	-0.19	-0.03	0.19
28	832898.8	811666.3	1490.6	1578.6	0.17	-0.07	0.19
29	820371.4	808386.4	1095.4	1754.8	-0.07	0.17	0.19
30	826735.4	822819.9	1227.1	1244.9	-0.14	0.09	0.16
31	843208.4	839171.6	1682.1	616.4	0.08	-0.14	0.16
32	843680.9	814490.9	1830.4	1427.1	-0.11	0.11	0.16
33	820839.9	826951.5	1010.8	1140.7	0.12	-0.06	0.13
34	820503.1	816978.1	1053.6	1471.1	0.09	0.08	0.12
35	822895.2	824598.6	1091	1207.1	-0.08	0.08	0.11

36	829623.1	823240.6	1320.1	1215.3	-0.08	0.07	0.11
37	841237.8	844802.2	1586.6	441.9	-0.09	0.04	0.1
38	832192.3	804361.7	1506.6	1823.2	0.08	0.05	0.09
39	851174	837882.3	1951.6	615.4	-0.02	-0.07	0.08
40	831652.8	812966.6	1442.4	1542.6	0.03	-0.06	0.07
41	840269.4	818253.1	1697.9	1321.6	0.04	0	0.04
42	833229.2	827038	1418.5	1070.5	-0.03	-0.03	0.04
43	838024.1	809520.3	1670.8	1621.6	-0.03	0.01	0.03
44	802367.5	806377.5	513.6	1918.1	0.03	0	0.03
45	819153.6	836864.8	901.5	823.5	0.02	-0.01	0.02
				RMSE	X	Y	Overall
					0.49	0.28	0.56

Table A3 Root Mean Square Error (RMSE) of the 42 Ground Control Points (GCPs) of 1997 SPOTand ordered from worse to best residuals

GCP	Georeferenced GCPs(meter)		Uncorrected GCPs (pixel)		Residual (pixel)		RMS Error
No.	X	Y	X	Y	X	Y	
1	846034.5	820453.9	1912.4	1476.1	-0.16	-0.94	0.96
2	846338.8	836588.8	1756.3	681.8	0.81	-0.38	0.89
3	829829.4	823769.4	1204.3	1460.8	-0.43	0.77	0.88
4	842236.3	836483.8	1586.3	724.9	-0.3	0.81	0.86
5	824308.4	825139.1	959.2	1442.9	0.59	0.57	0.82
6	845279.4	838326.9	1693.6	605.6	0.36	-0.71	0.8
7	829356.9	808630.6	1346.3	2208.8	0.57	0.54	0.79
8	836389.1	834309.7	1366.6	882.6	0.14	-0.75	0.77
9	835702.3	815943.6	1532.3	1790.9	-0.17	-0.71	0.73
10	831869.4	821256.9	1316.9	1564.4	0.28	-0.68	0.73
11	827849.4	820799.4	1152.9	1624.1	-0.57	0.42	0.71
12	852436.3	841298.8	1957.1	396.9	-0.36	0.61	0.7
13	838241.6	820187.2	1593.6	1559.9	0.56	-0.39	0.69
14	811584.7	831930.3	348.1	1223.1	0.65	-0.14	0.66
15	842029.1	836539.1	1577.1	723.8	-0.37	0.54	0.65
16	821256.9	826776.9	813.1	1389.8	0.45	0.44	0.63
17	840270.3	818252.2	1697.1	1637.4	-0.48	0.36	0.6
18	815648.3	826944.2	573.6	1432.1	-0.22	0.5	0.55
19	810293.3	825348.6	363.3	1558.1	-0.51	-0.16	0.54
20	844633	824266.7	1814.7	1302.9	0.02	0.53	0.53
21	820588.4	837774.7	666.6	855.1	0.49	-0.16	0.51
22	845477.2	815959.1	1937.1	1703.1	0.45	0.23	0.5
23	838972.9	827917.9	1542.2	1173.9	0.45	-0.05	0.45
24	822523.4	840358.4	719.7	710.8	-0.37	-0.24	0.44
25	819295.6	812654.4	881.4	2100.6	0.08	-0.41	0.42
26	837934.1	834596.6	1427.4	855.4	-0.42	-0.04	0.42
27	843213.1	814878.1	1854.9	1776.7	0.28	0.31	0.42
28	822221.6	820209.7	923.2	1703.4	-0.4	0.1	0.41
29	820363	808383.6	972	2301	0.15	-0.37	0.4
30	844566.9	813614.4	1923.3	1826.3	-0.39	0.05	0.39

31	840105.3	806167.8	1817.4	2232.6	-0.34	0.17	0.38
32	843603.1	835090.6	1658.1	779.9	0.11	-0.35	0.37
33	821661.9	836290.6	727.1	918.6	-0.34	0.13	0.37
34	832170.3	819977.2	1342.4	1625.1	-0.3	-0.15	0.33
35	836689.1	816154.1	1571.4	1772.1	0.17	-0.27	0.32
36	839783.8	819346.3	1665.6	1587.9	-0.25	0.17	0.3
37	817210.6	825914.4	650.9	1467.9	-0.12	-0.22	0.25
38	852729.7	826292.2	2126.9	1130.3	0.18	0.15	0.23
39	840440.2	829847.4	1582.1	1065.9	-0.13	-0.17	0.22
40	856915.2	830316.4	2256.1	894.9	-0.14	-0.13	0.19
41	810112.8	807626.6	547.4	2431.1	-0.03	0.09	0.09
42	801373	808776.4	163.3	2453.3	0.01	-0.06	0.06
				RMSE	X	Y	overall
					0.40	0.47	0.62

APPENDIX B PRINCIPAL COMPONENTS OF BIOPHYSICAL DATA

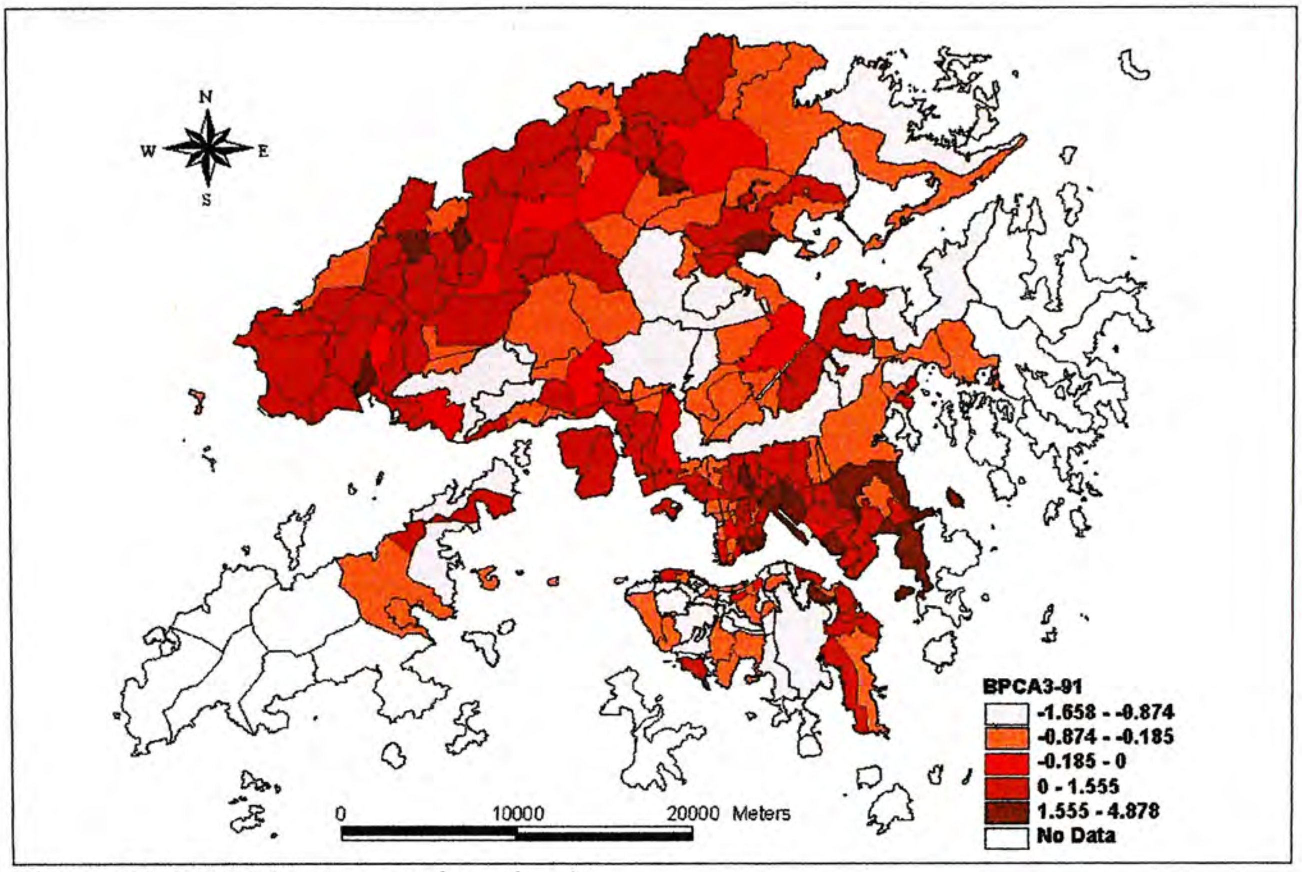

Figure B1 BPCA1$_{91}$ (vegetation vigor)

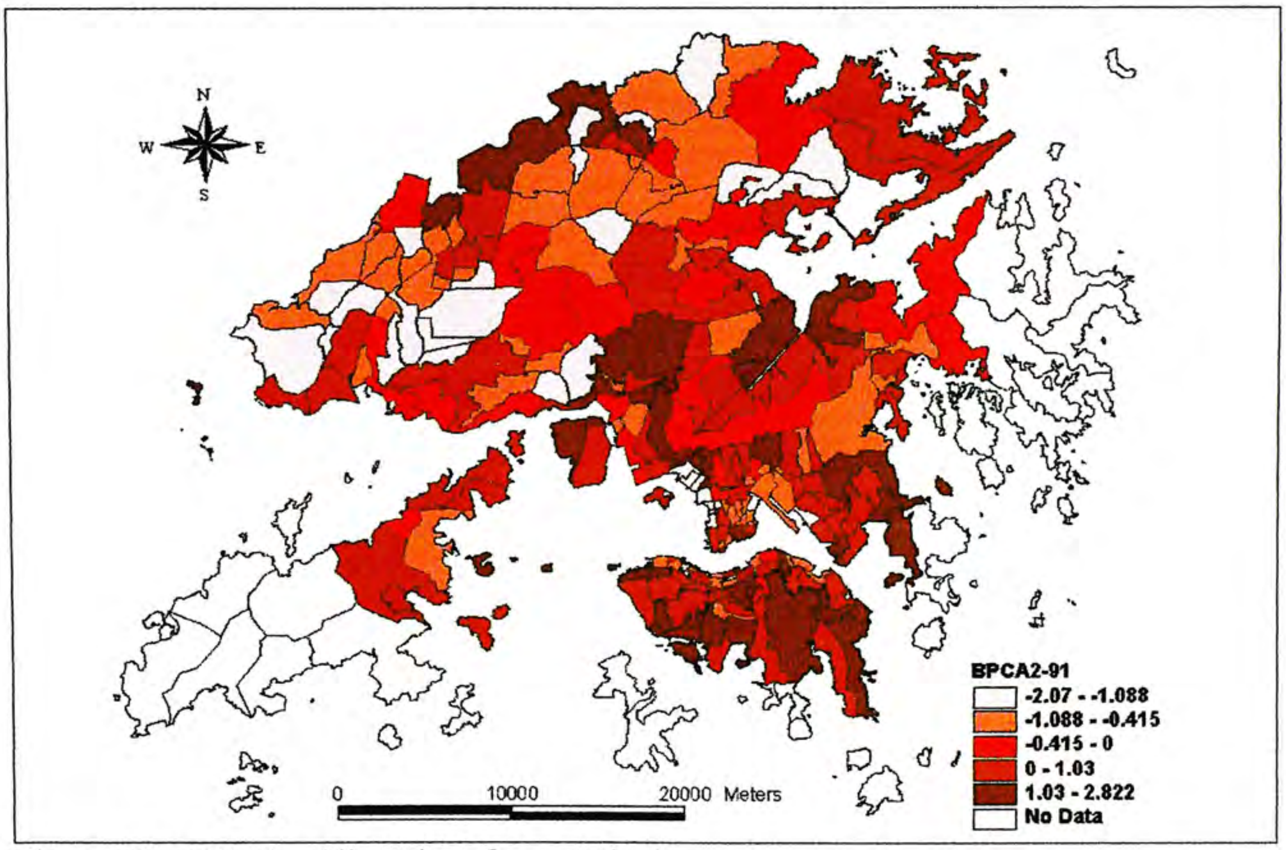

Figure B2 BPCA2$_{91}$ (diversity of vegetation)

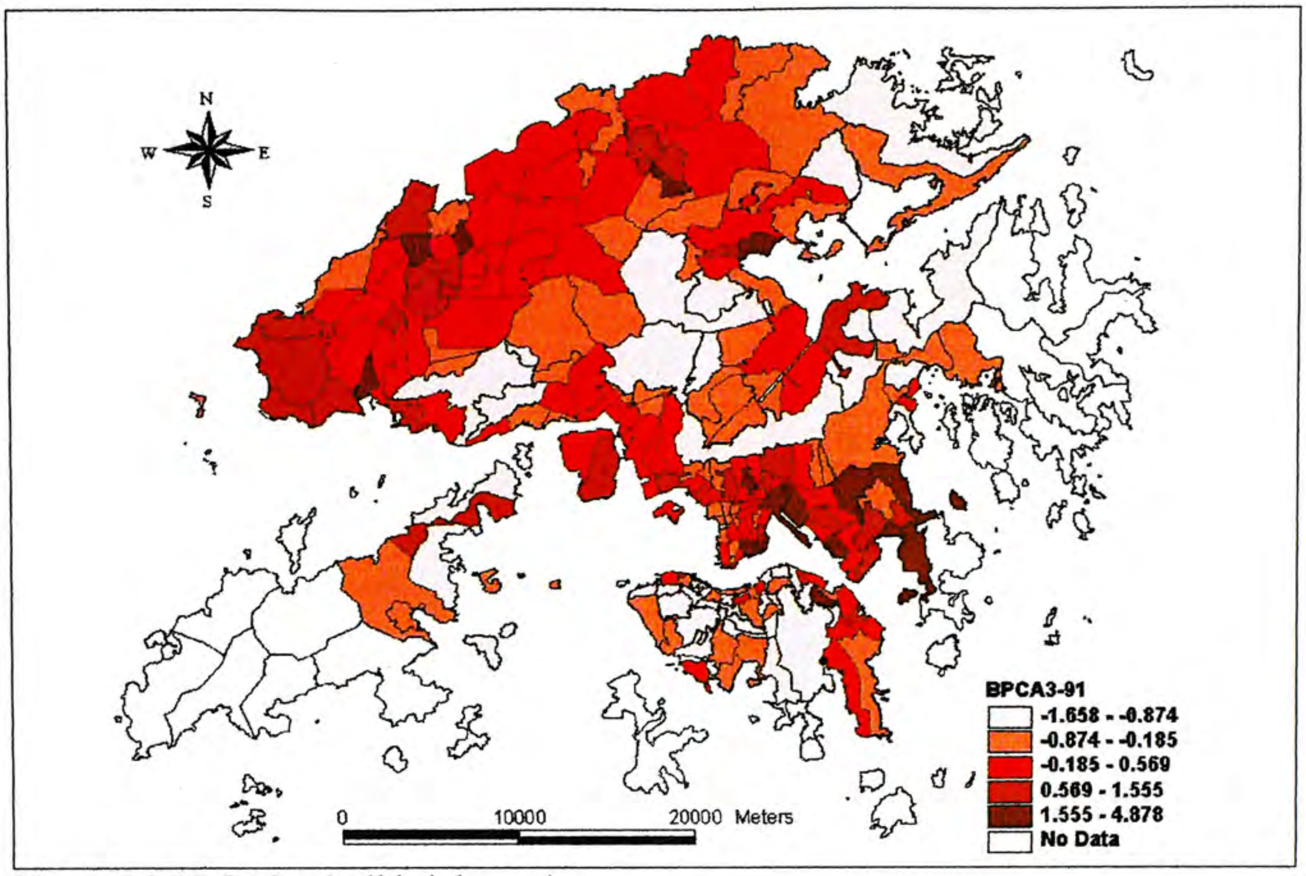

Figure B3 BPCA3$_{91}$ (soil brightness)

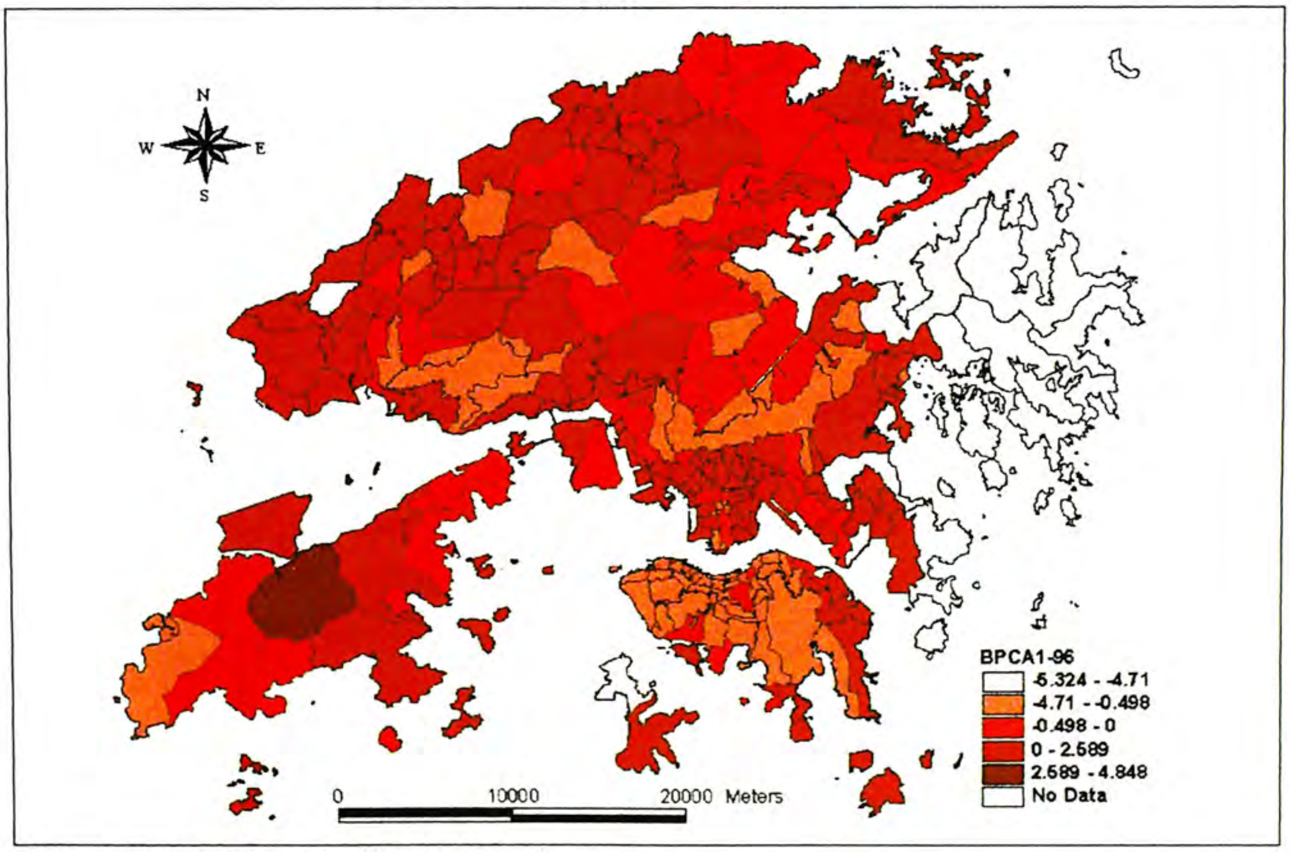

Figure B4 BPCA1$_{96}$ (soil brightness)

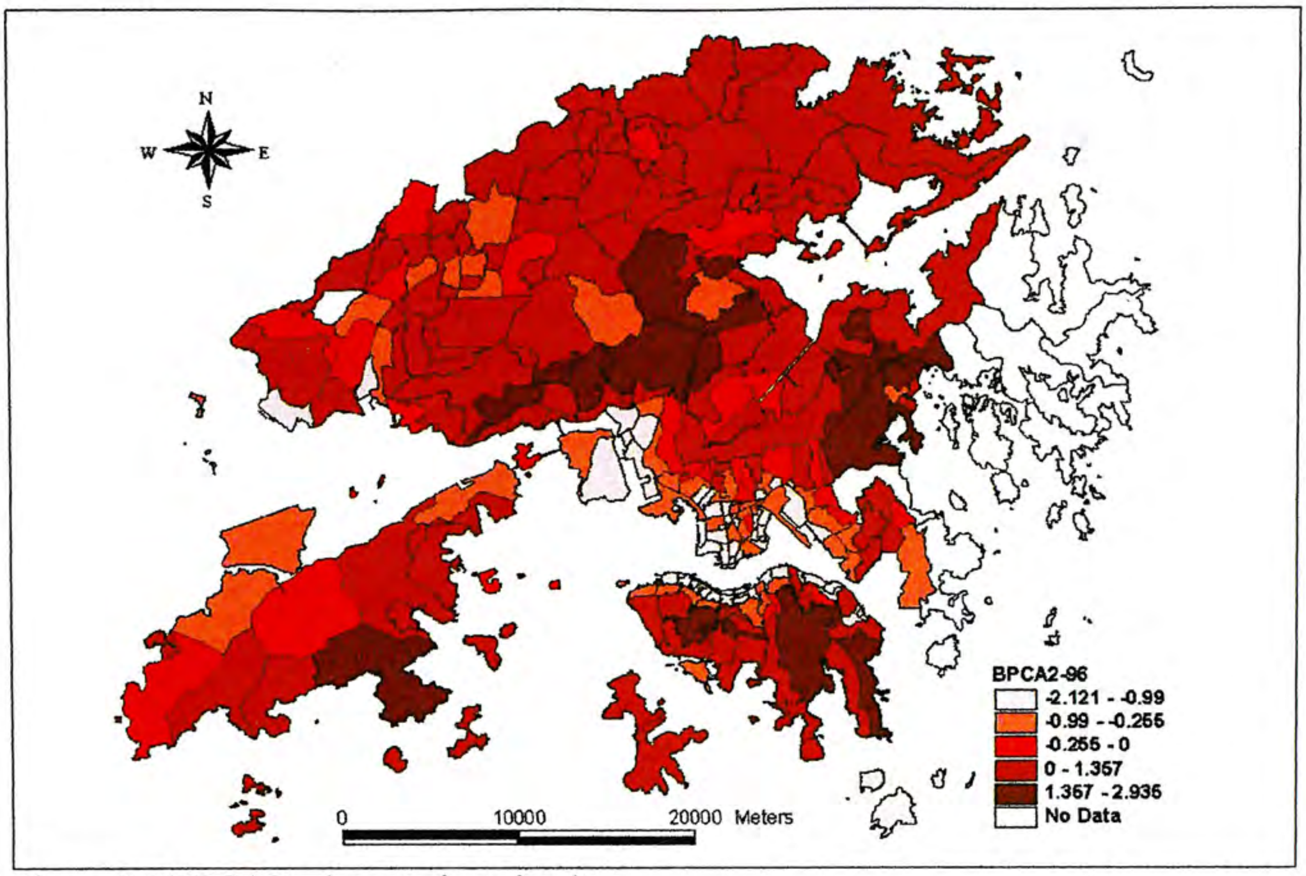

Figure B5 BPCA2$_{96}$ (vegetation vigor)

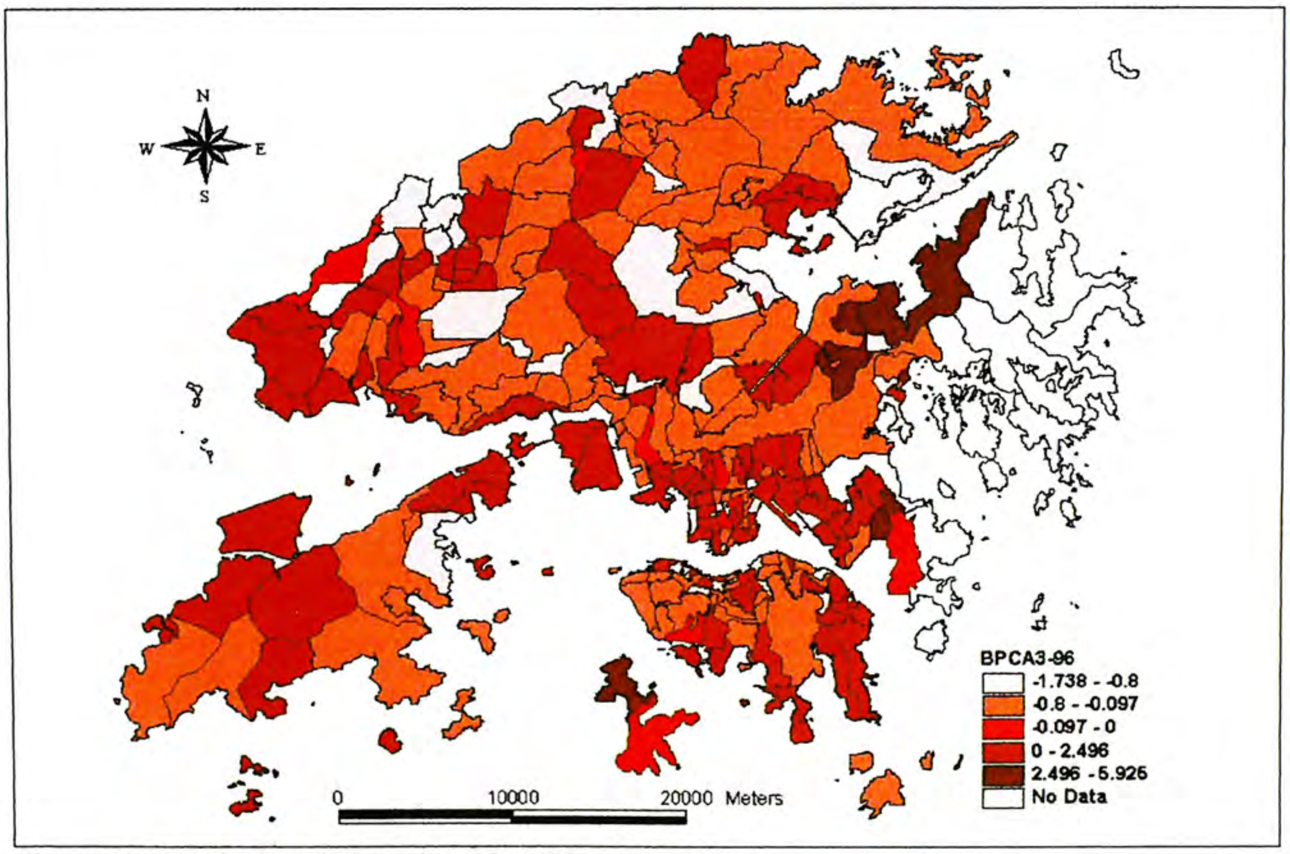

Figure B6 BPCA3$_{96}$ (diversity of soil brightness)

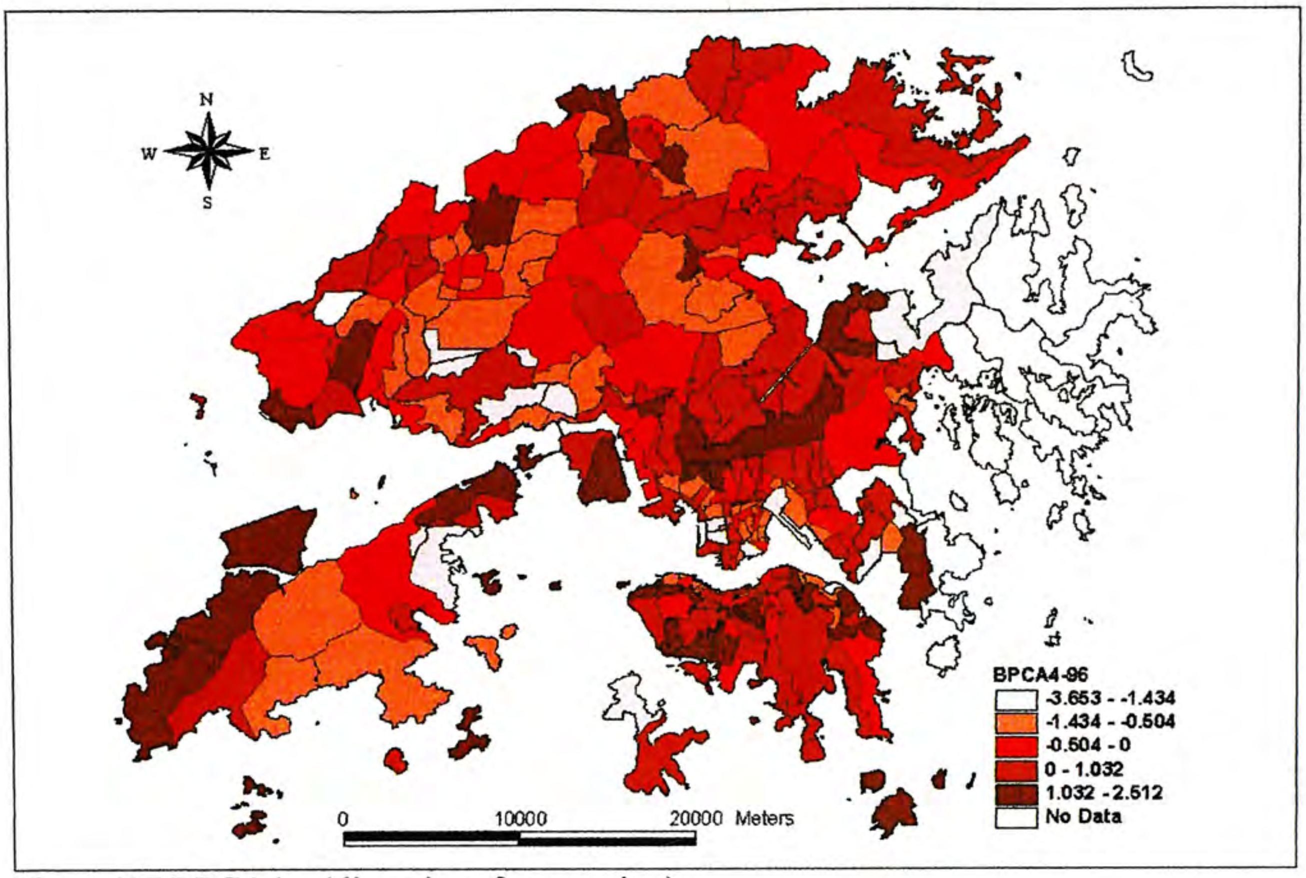

Figure B7 BPCA4$_{96}$ (diversity of vegetation)

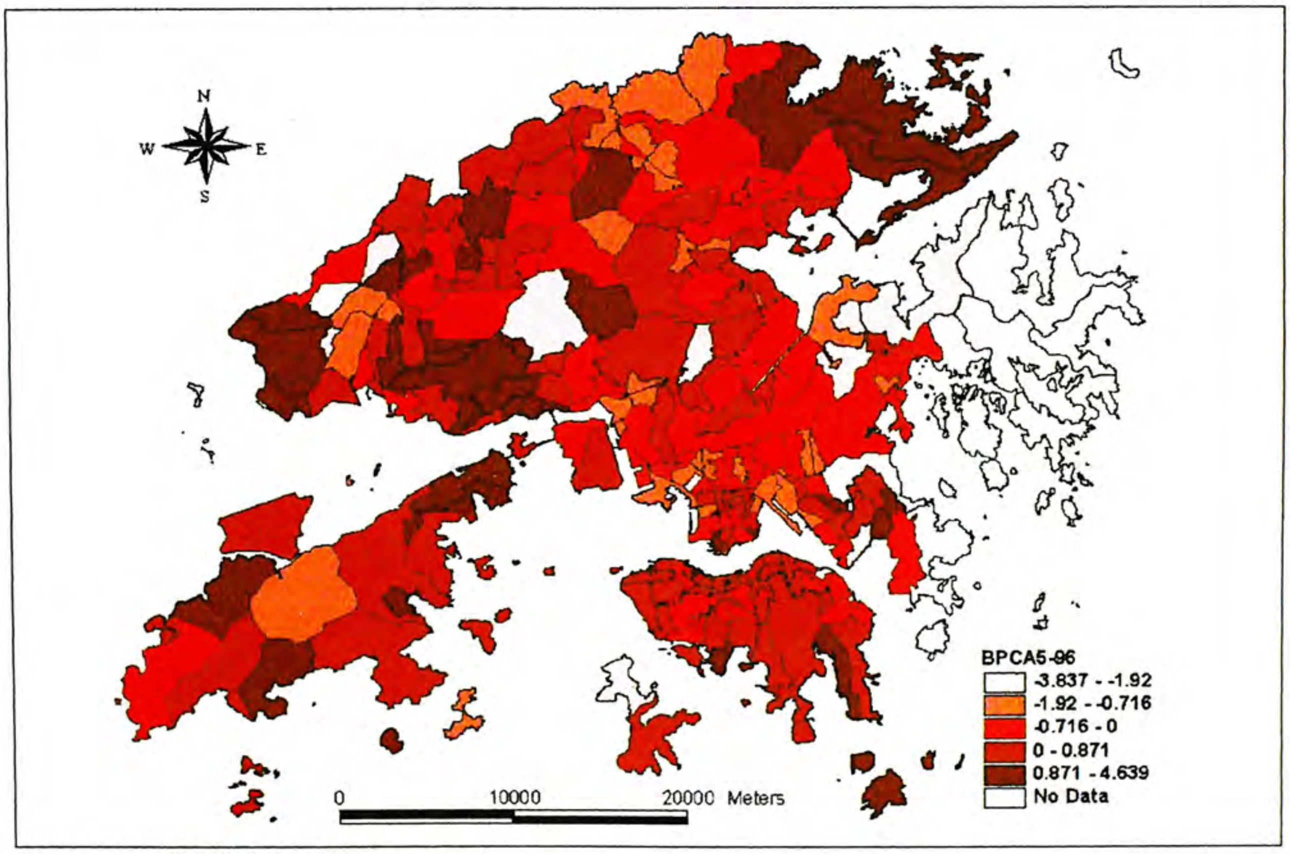

Figure B8 BPCA5$_{96}$ (water area)

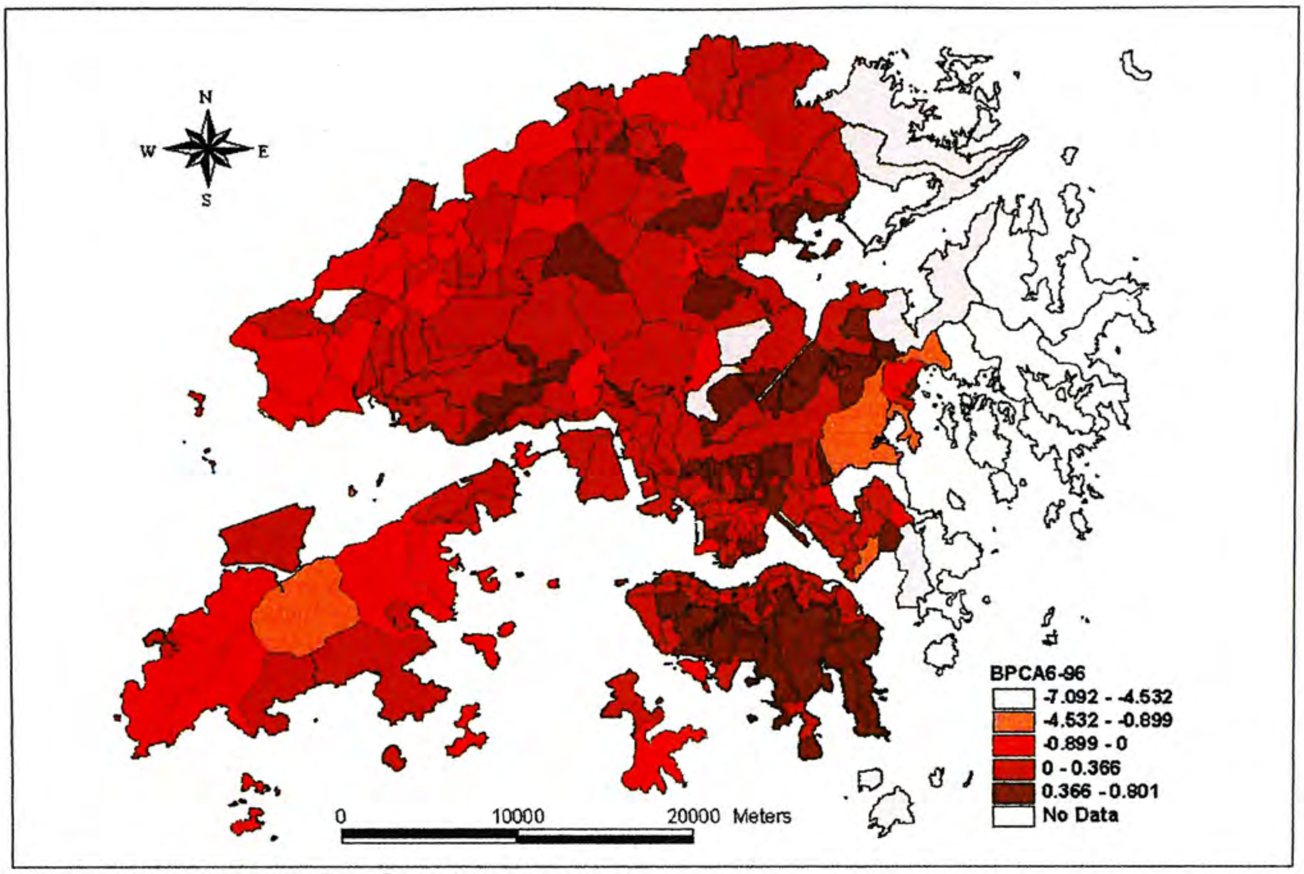

Figure B9 BPCA6_{96} (surface temperature)

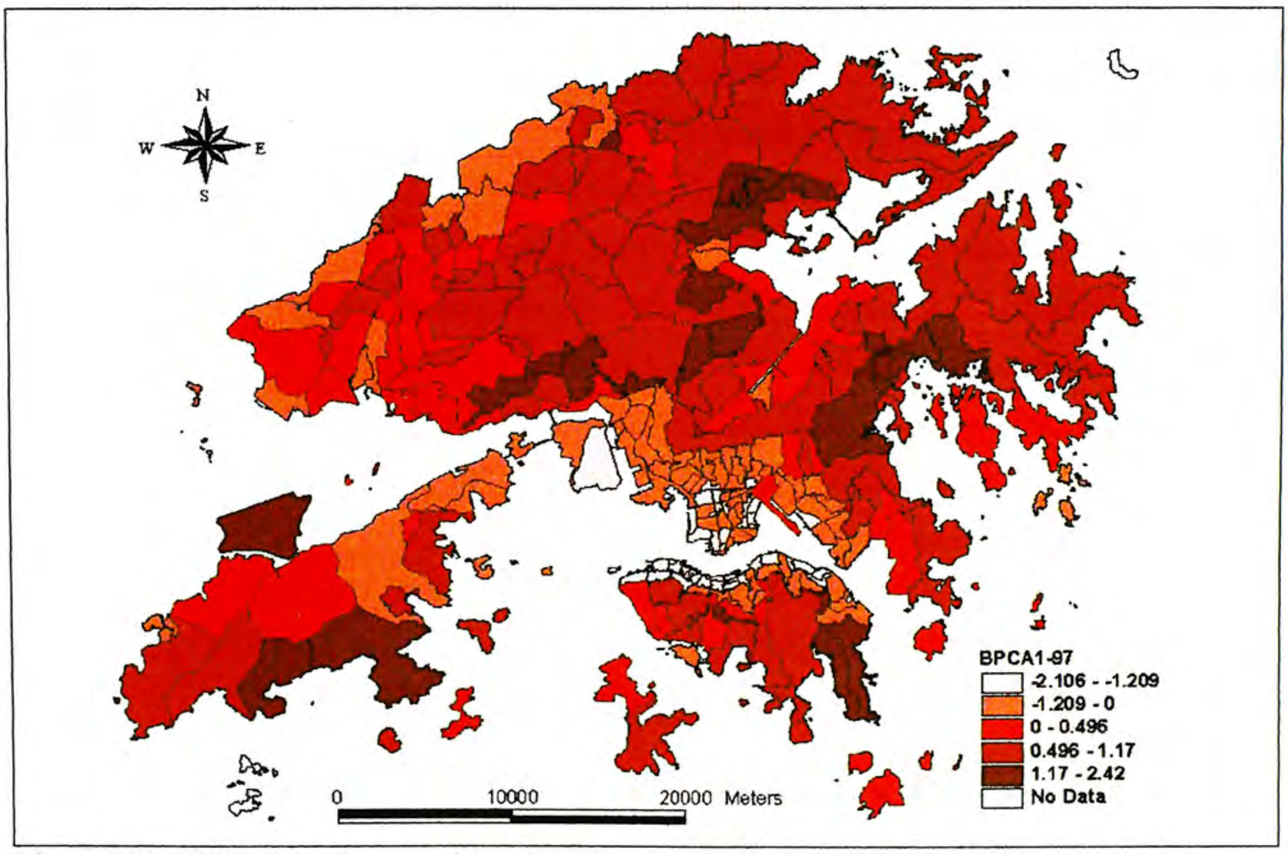

Figure B10 BPCA1_{97} (vegetation vigor)

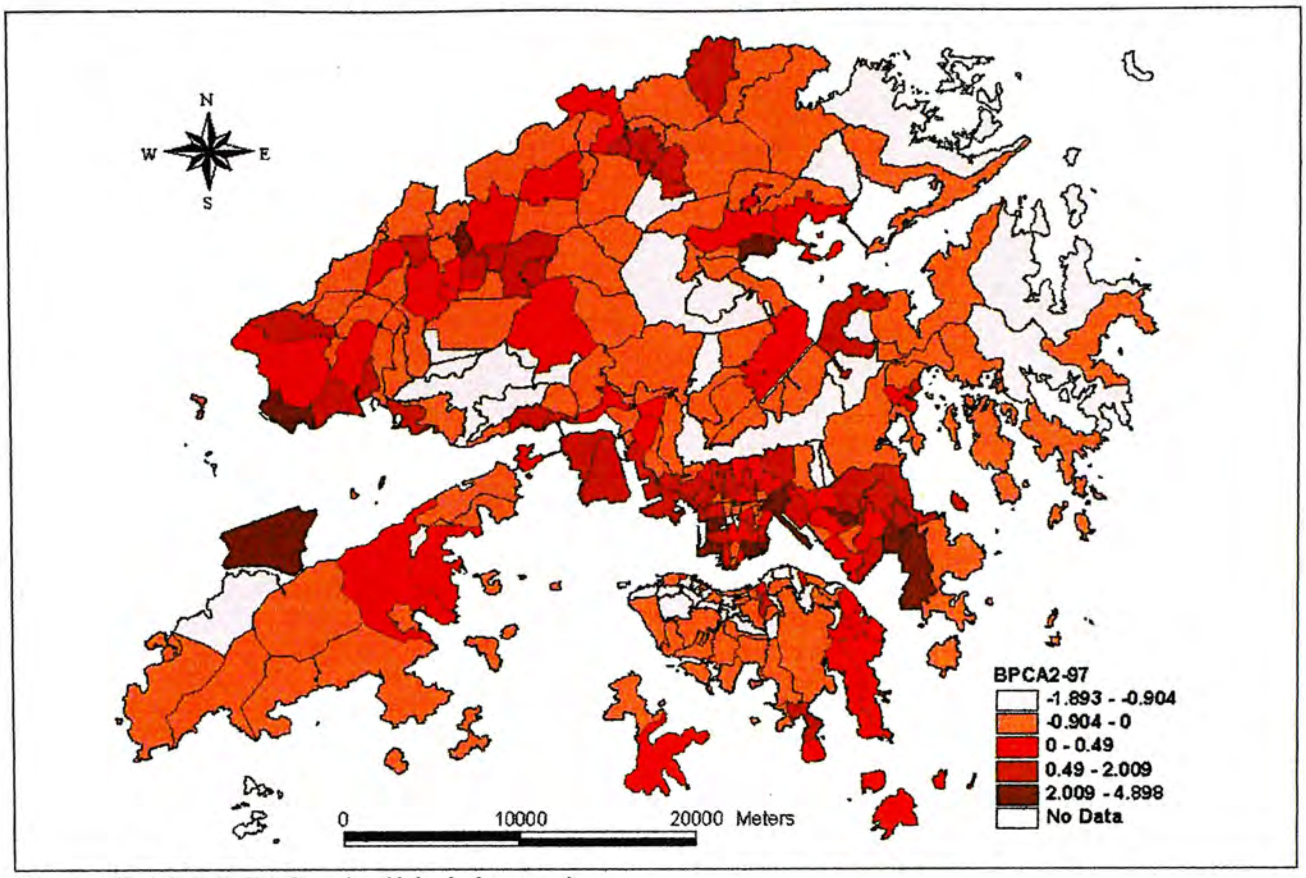

Figure B11 BPCA2_{97} (soil brightness)

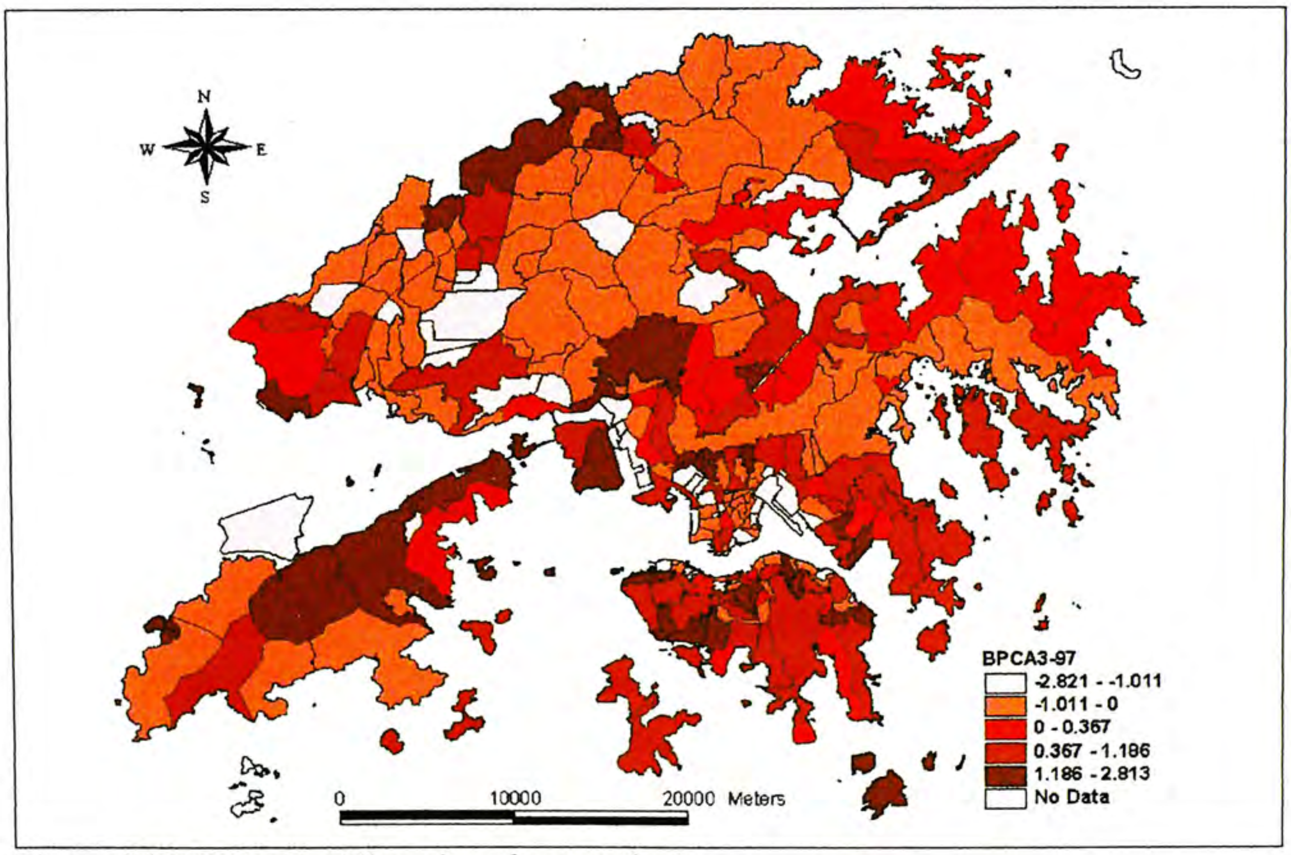

Figure B12 BPCA3_{97} (diversity of vegetation)

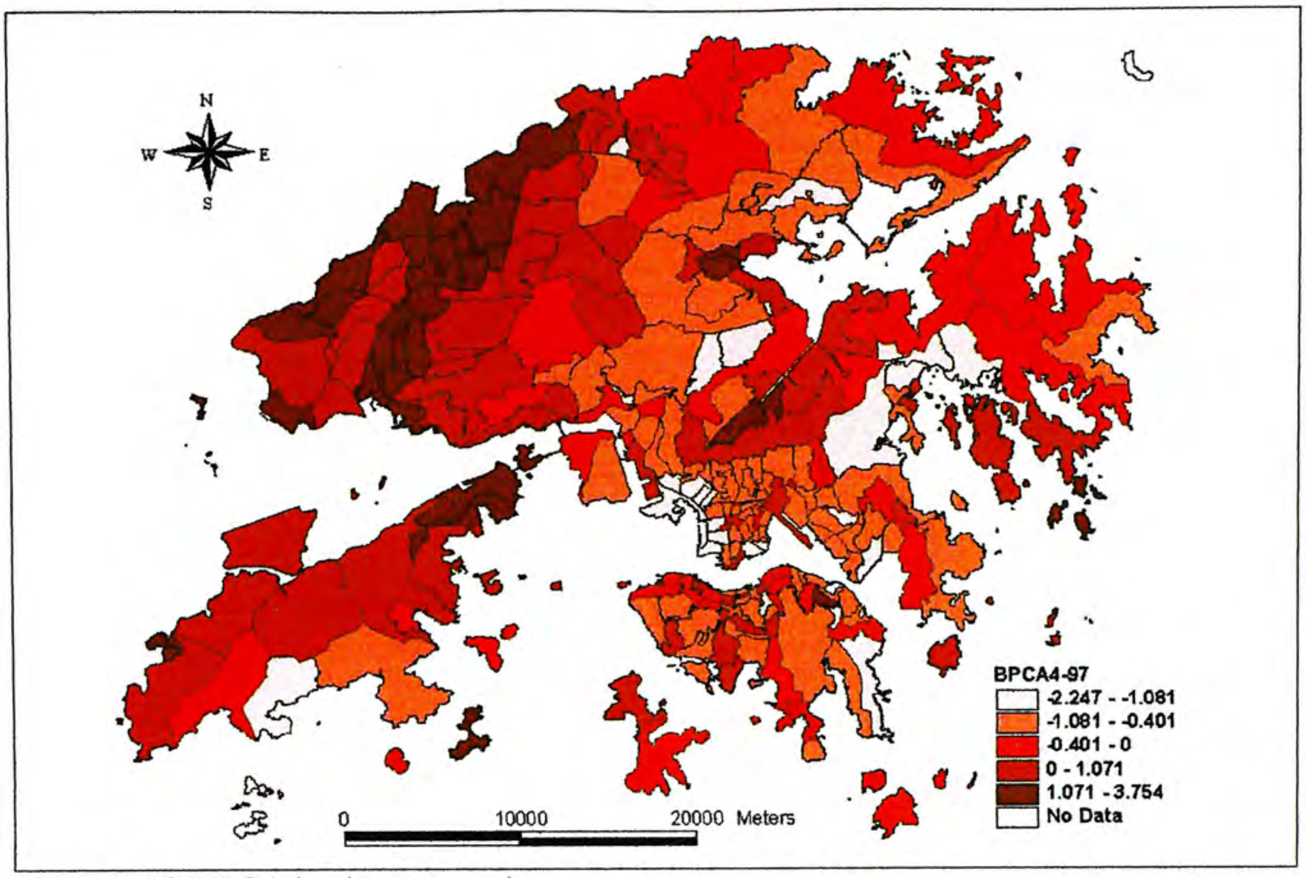

Figure B13 BPCA4$_{97}$ (water area)

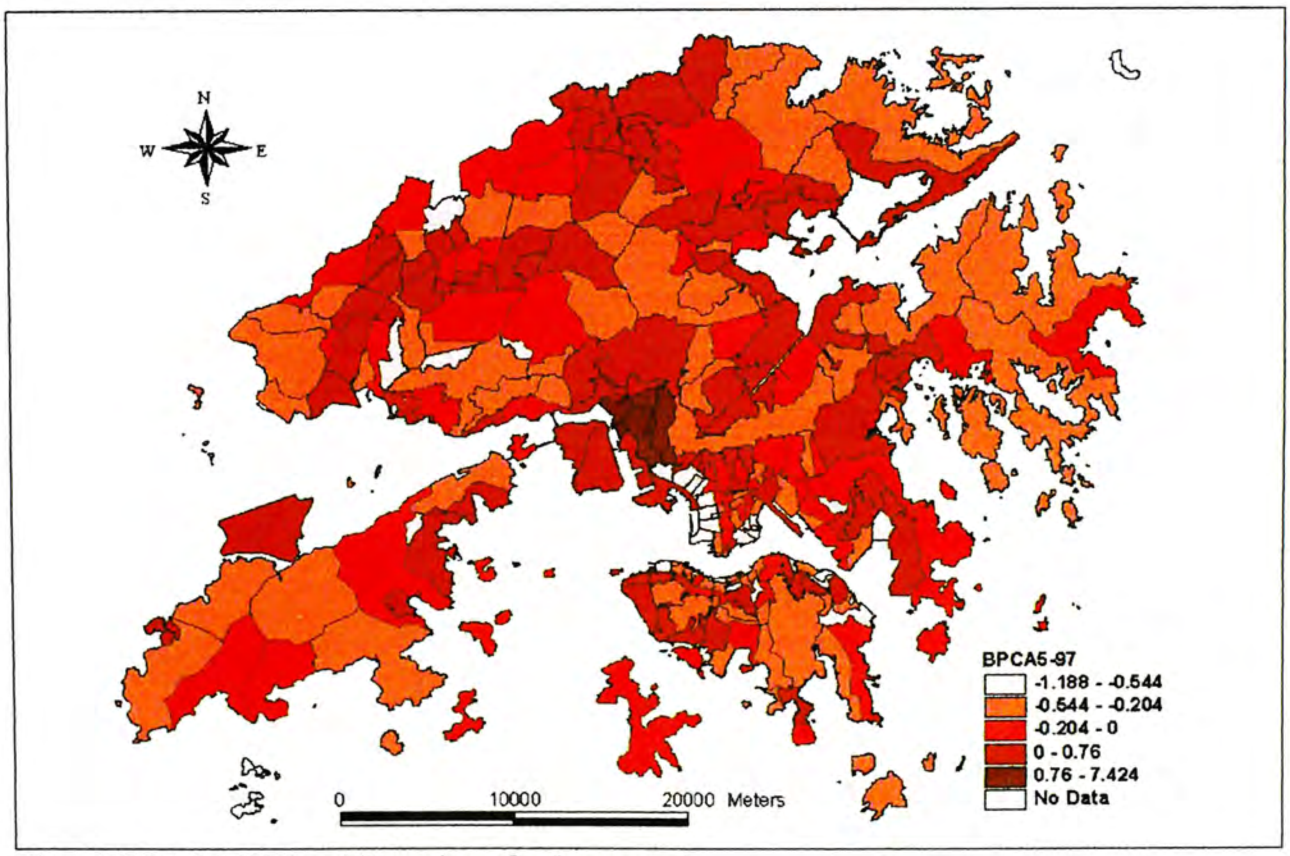

Figure B14 BPCA5$_{97}$ (diversity of urban area)

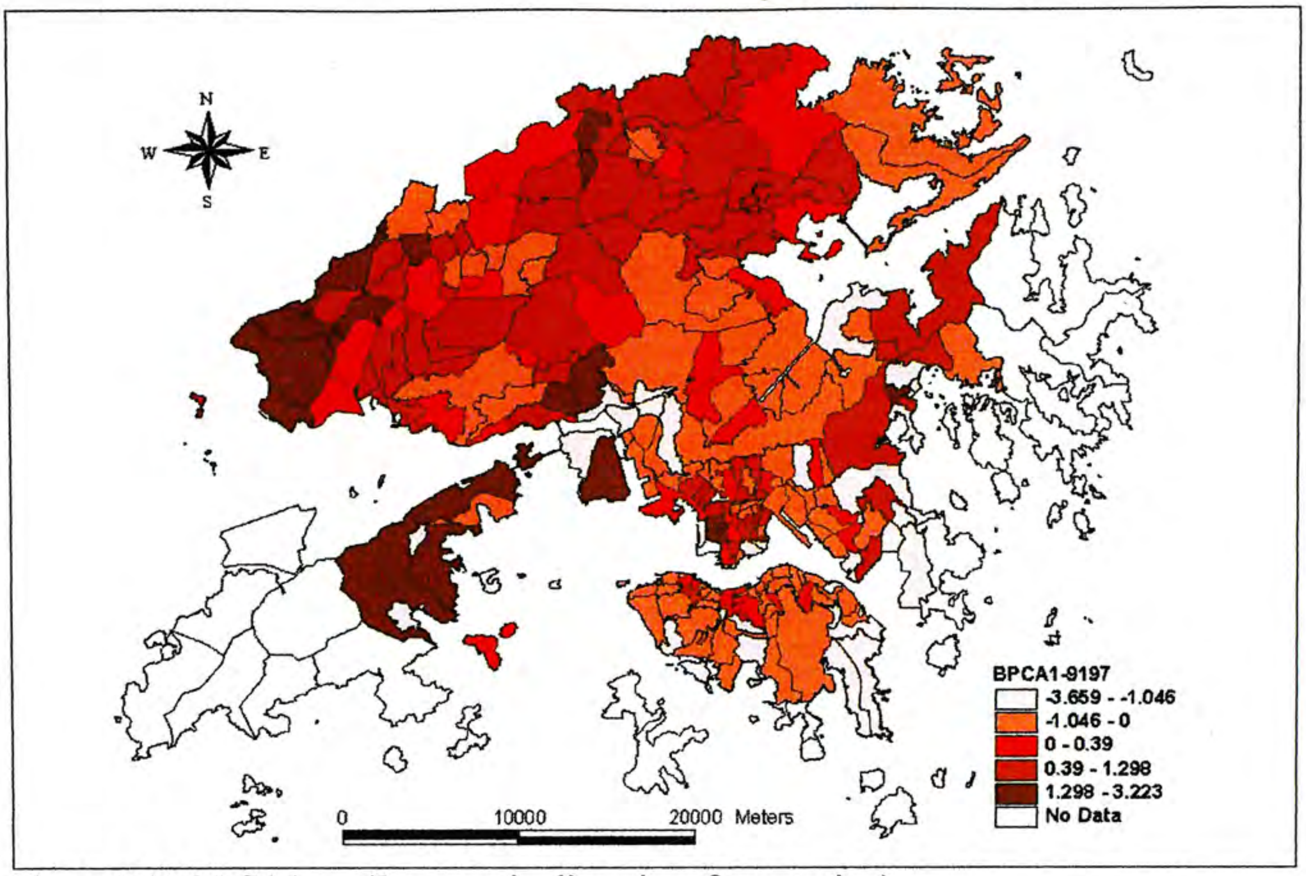

Figure B15 BPCA1$_{9197}$ (Increase in diversity of vegetation)

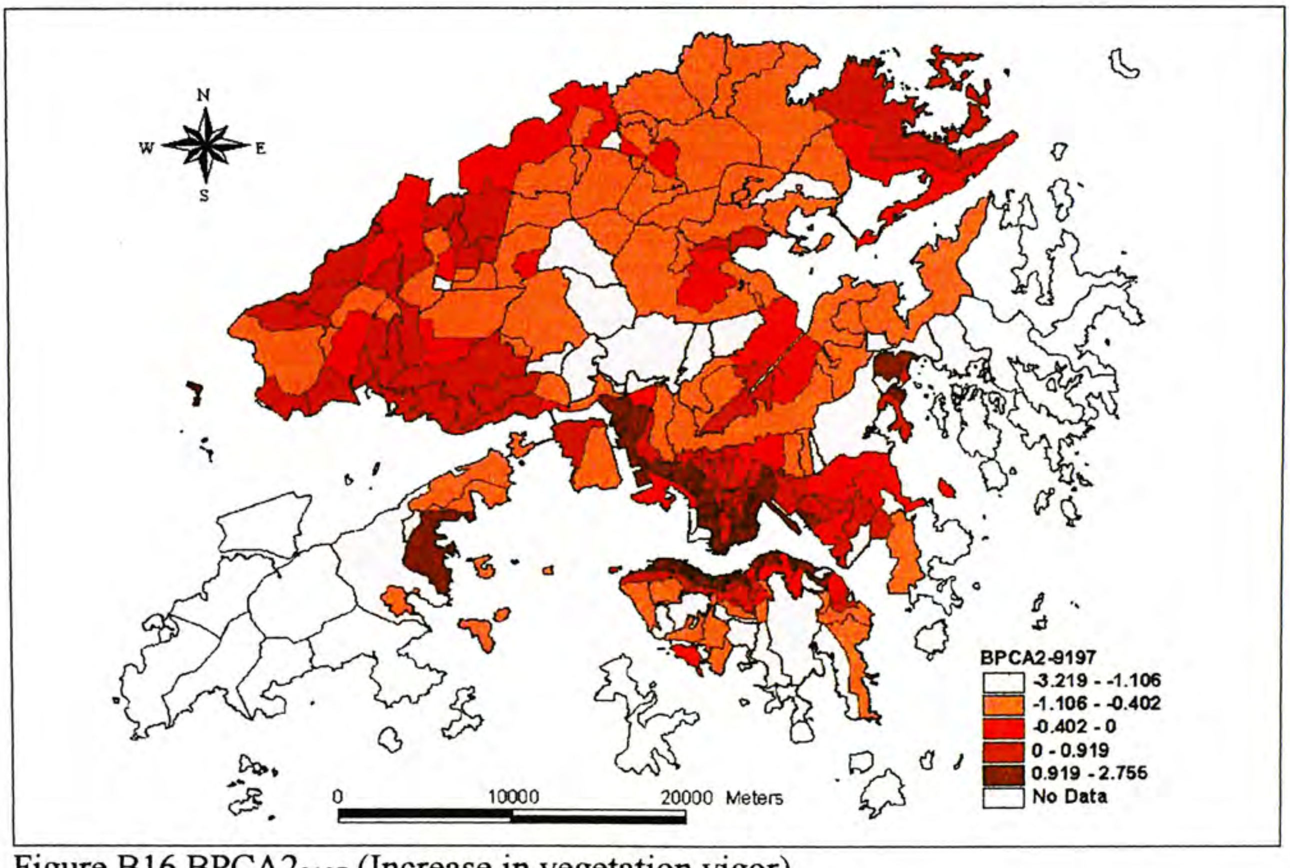

Figure B16 BPCA2$_{9197}$ (Increase in vegetation vigor)

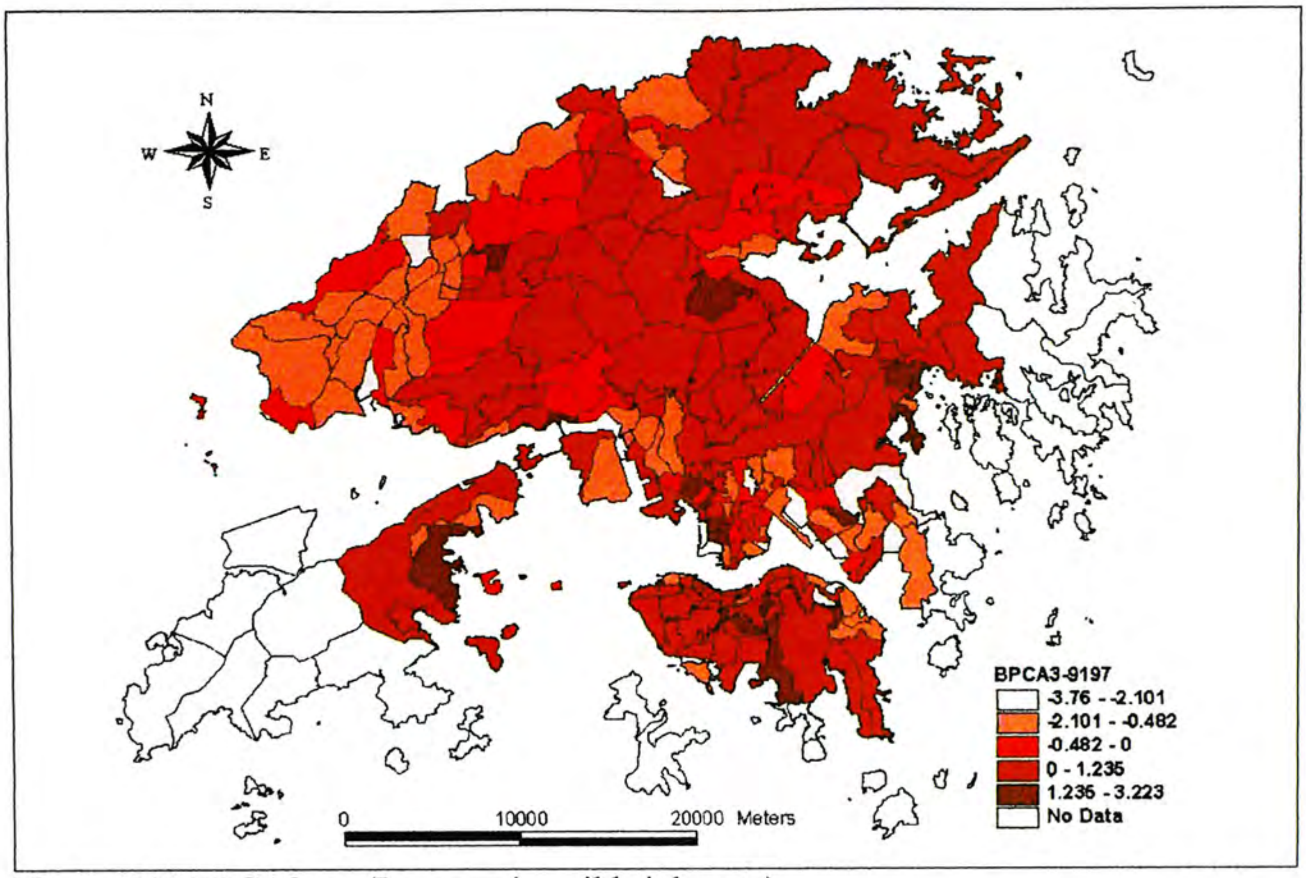

Figure B17 BPCA3$_{9197}$ (Increase in soil brightness)

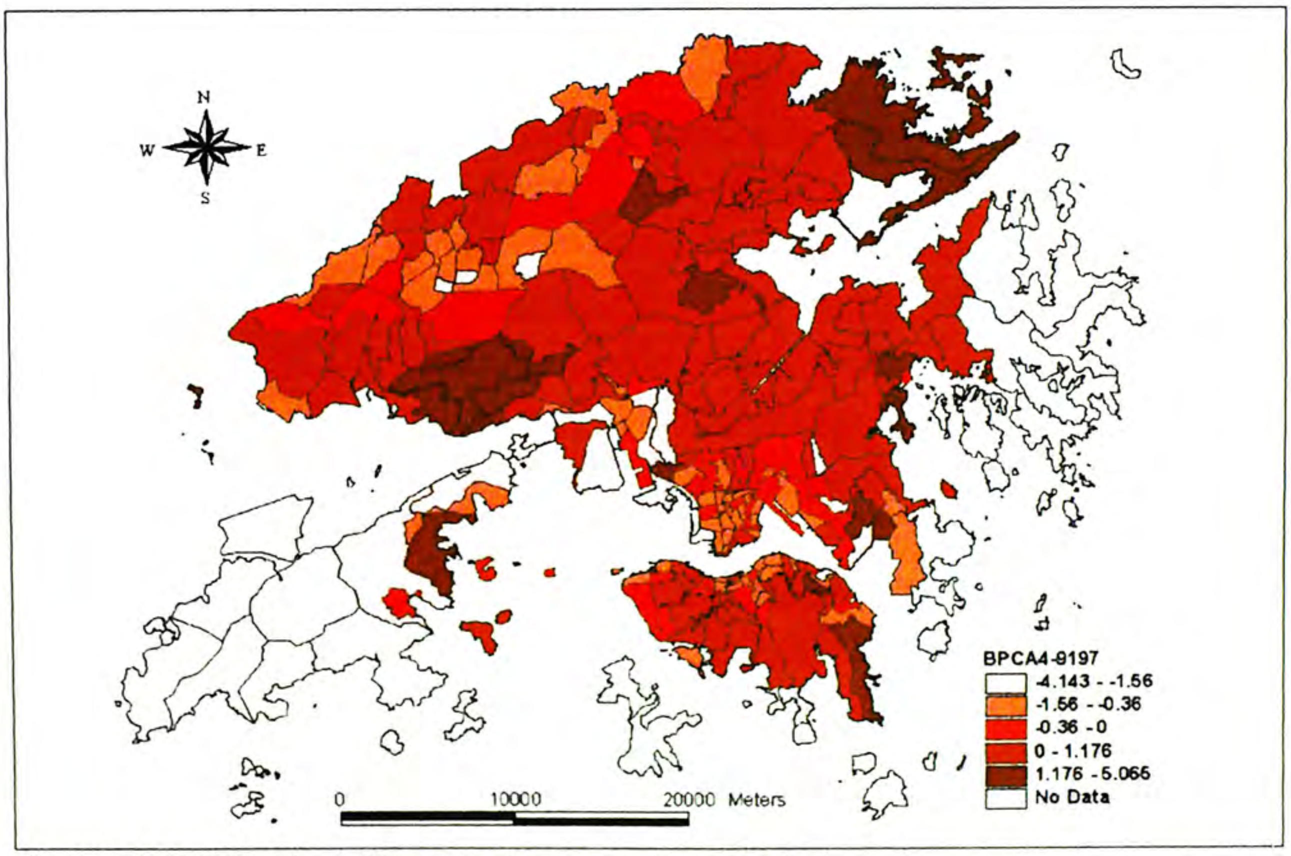

Figure B18 BPCA4$_{9197}$ (Increase in vegetation vigor)

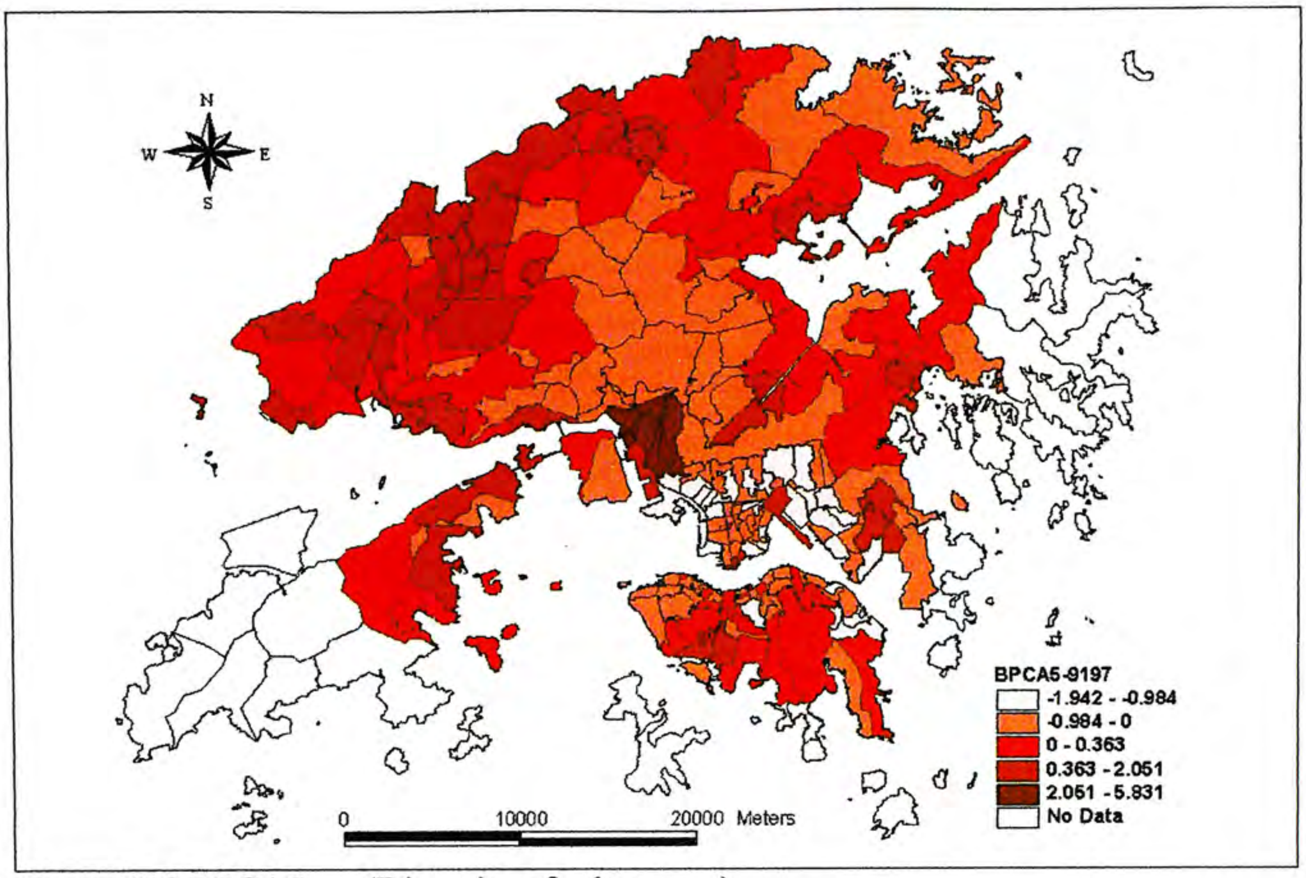

Figure B19 BPCA5$_{9197}$ (Diversity of urban area)

APPENDIX C PRINCIPAL COMPONENTS OF SOCIOECONOMIC DATA

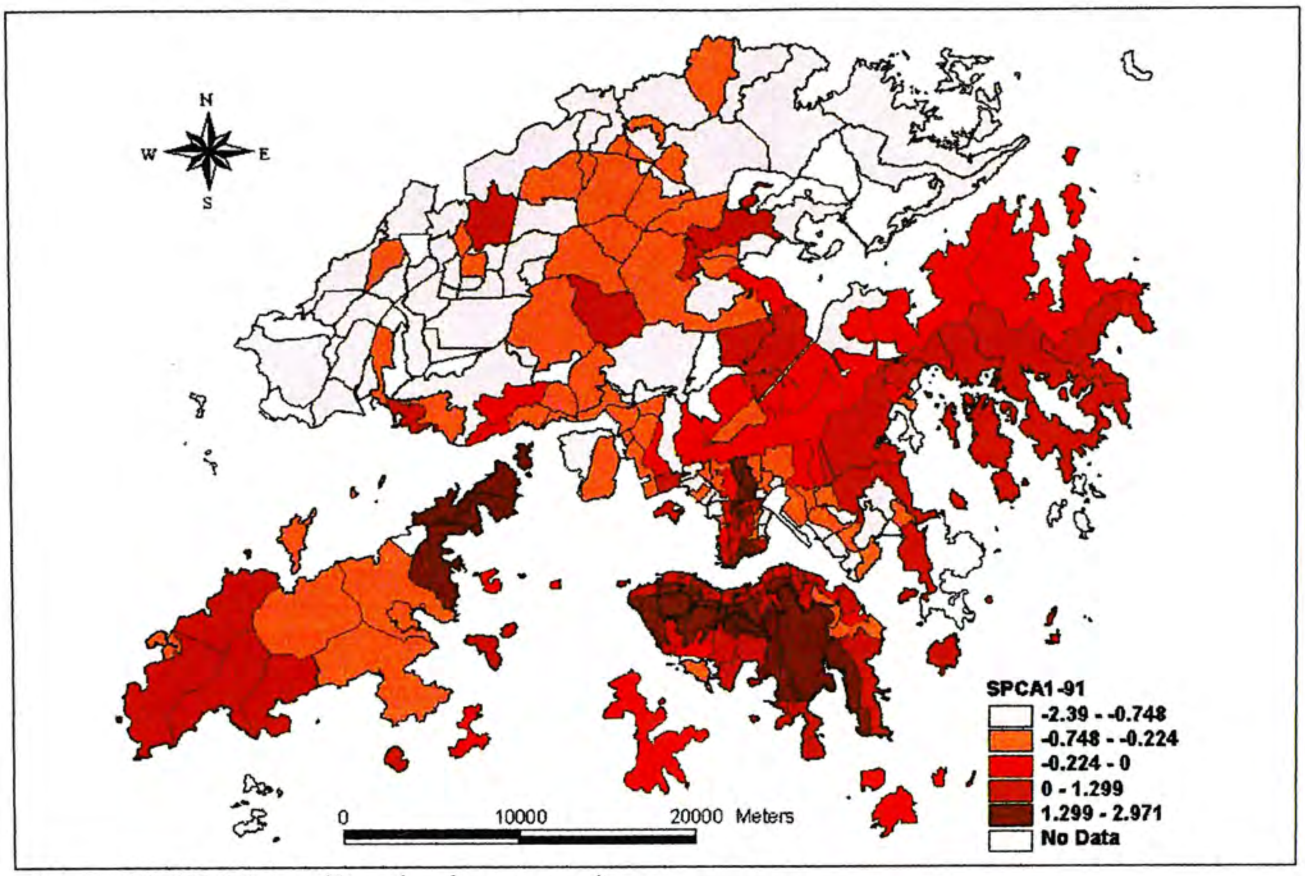

Figure C1 SPCA1_{91} (Purchasing power)

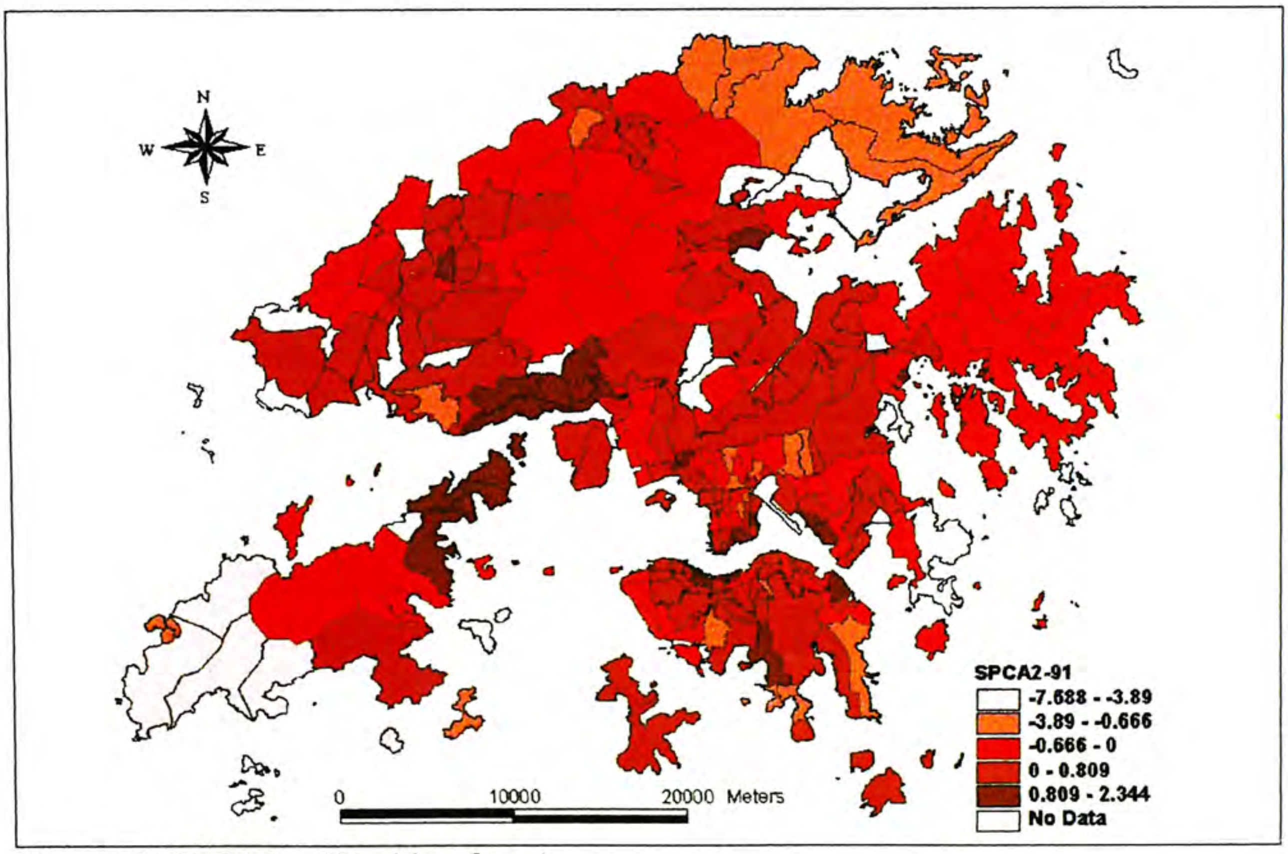

Figure C2 SPCA2_{91} (Working force)

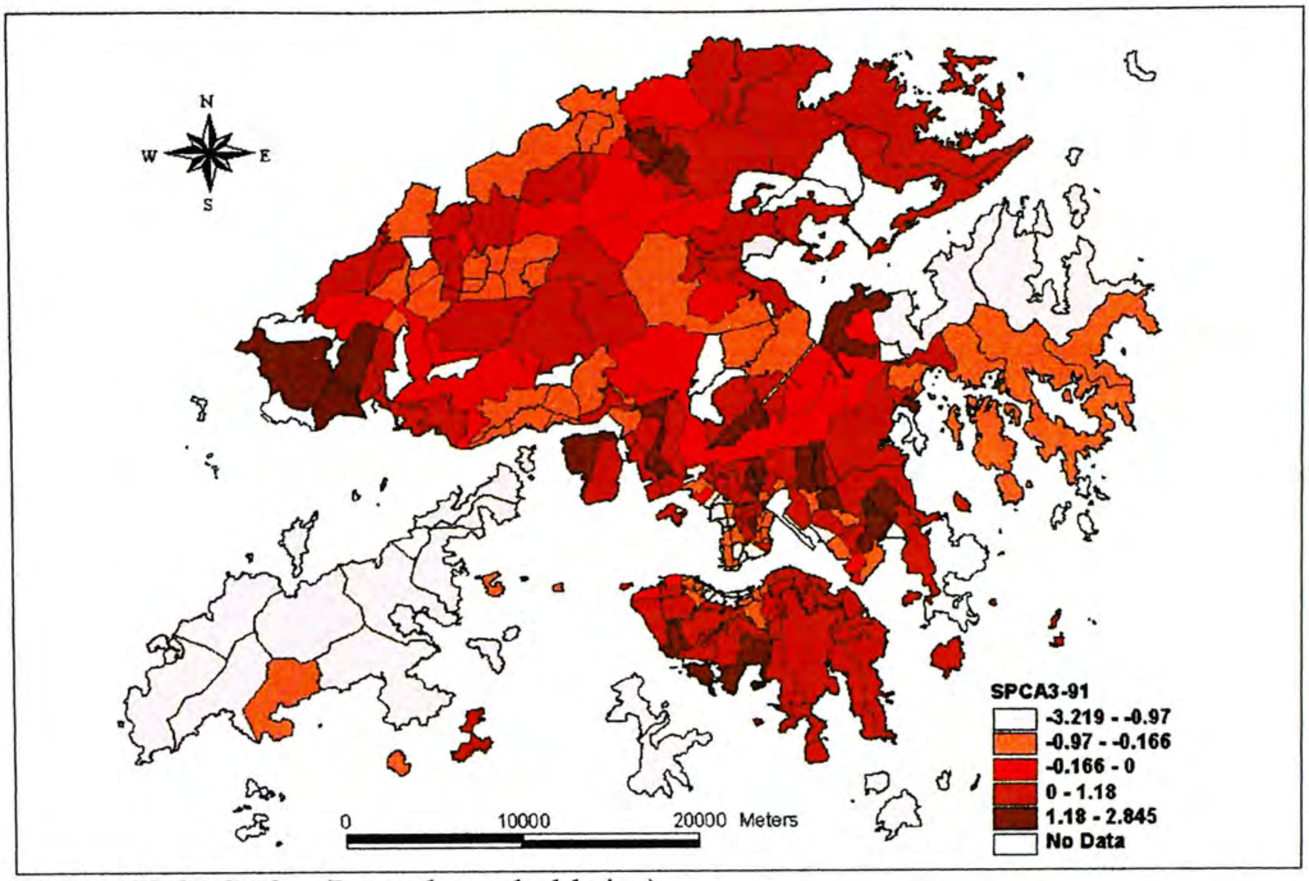

Figure C3 $SPCA3_{91}$ (Large household size)

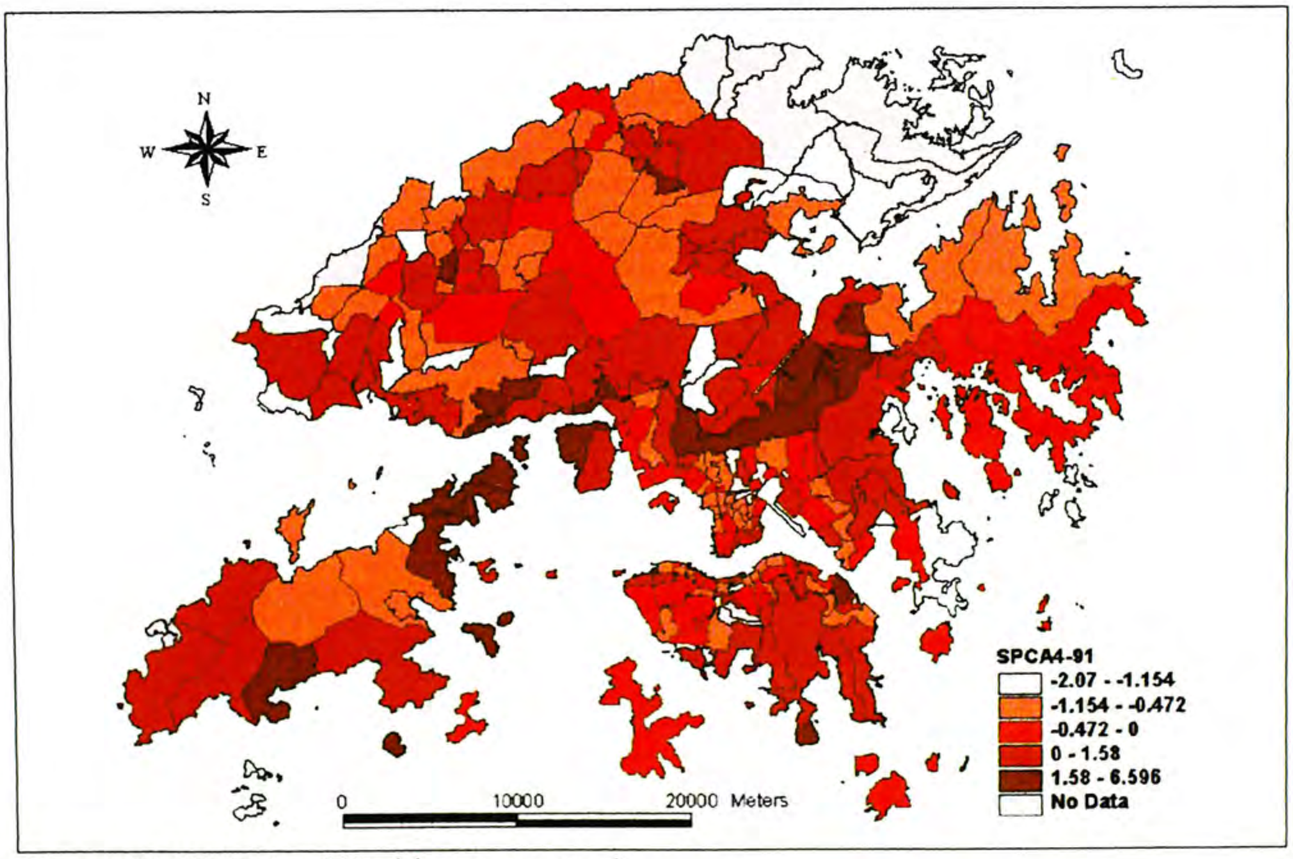

Figure C4 $SPCA4_{91}$ (Working age group)

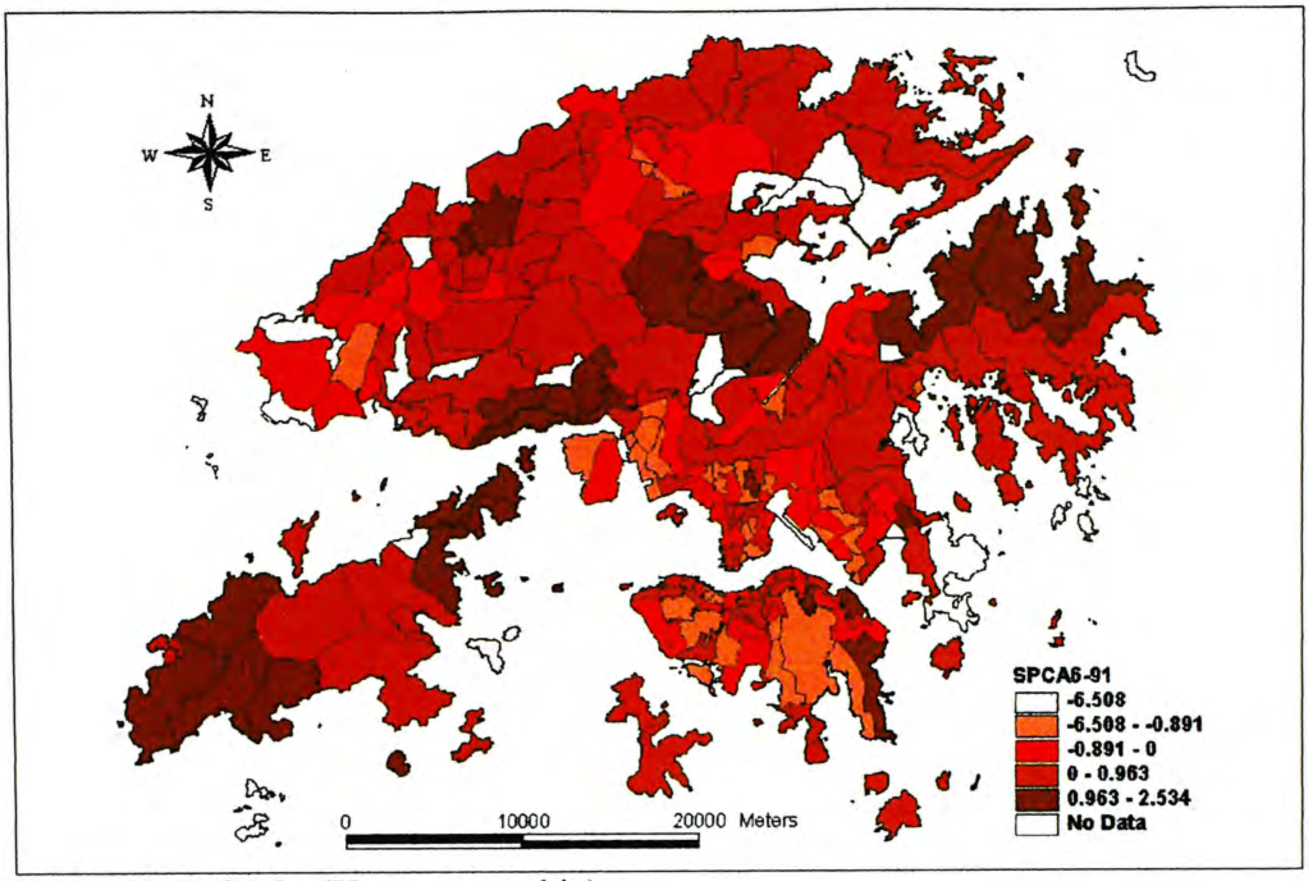

Figure C5 SPCA6$_{91}$ (Home ownership)

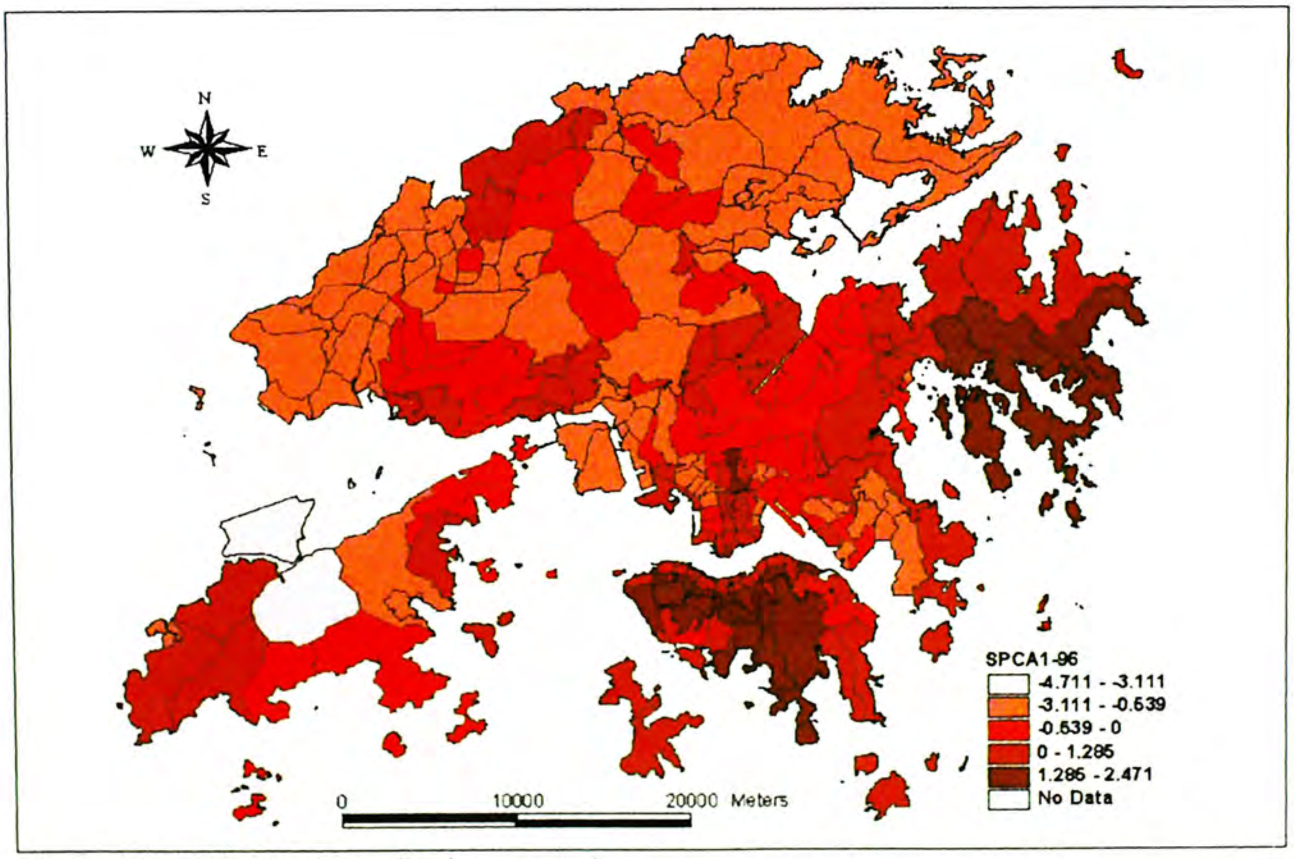

Figure C6 SPCA1$_{96}$ (Purchasing power)

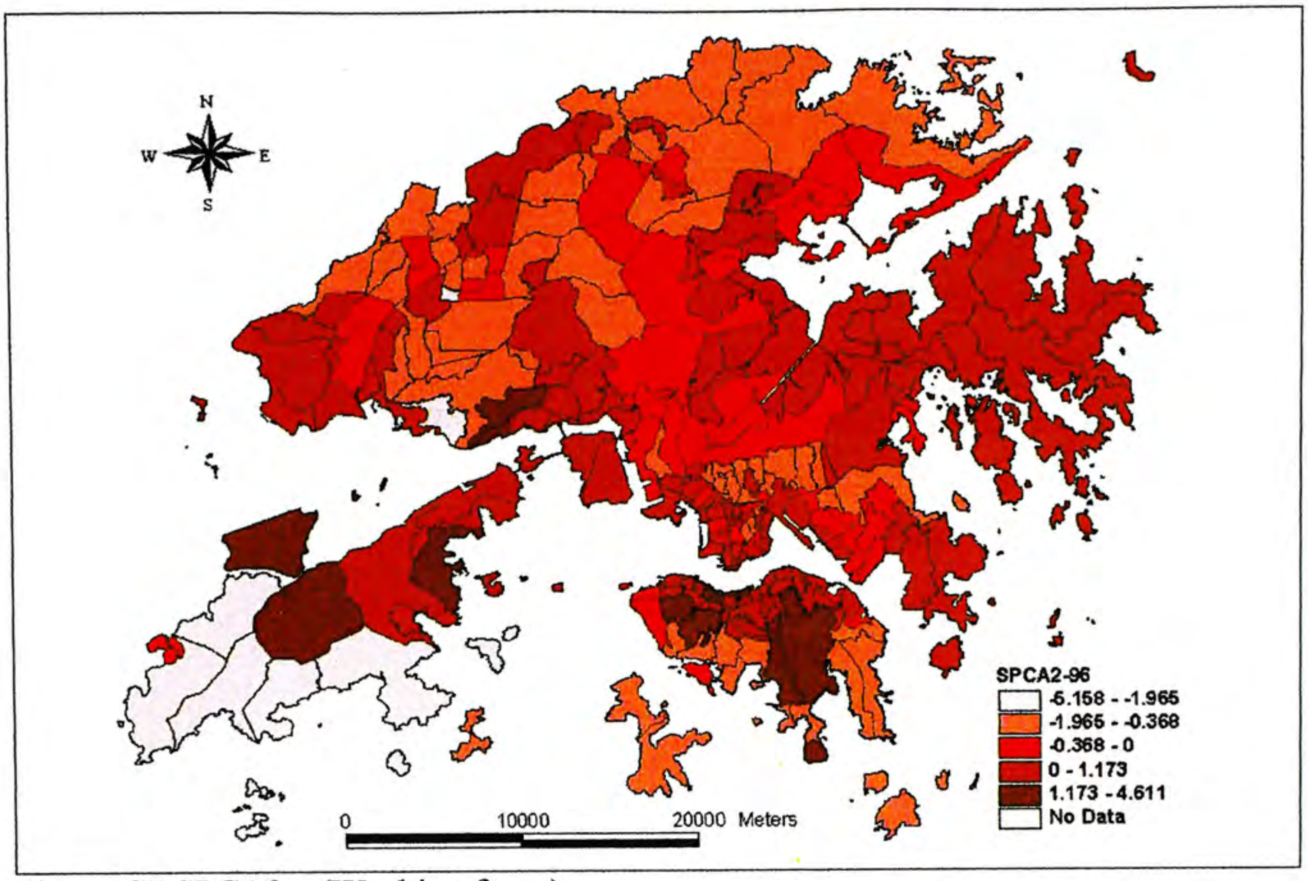

Figure C7 SPCA2$_{96}$ (Working force)

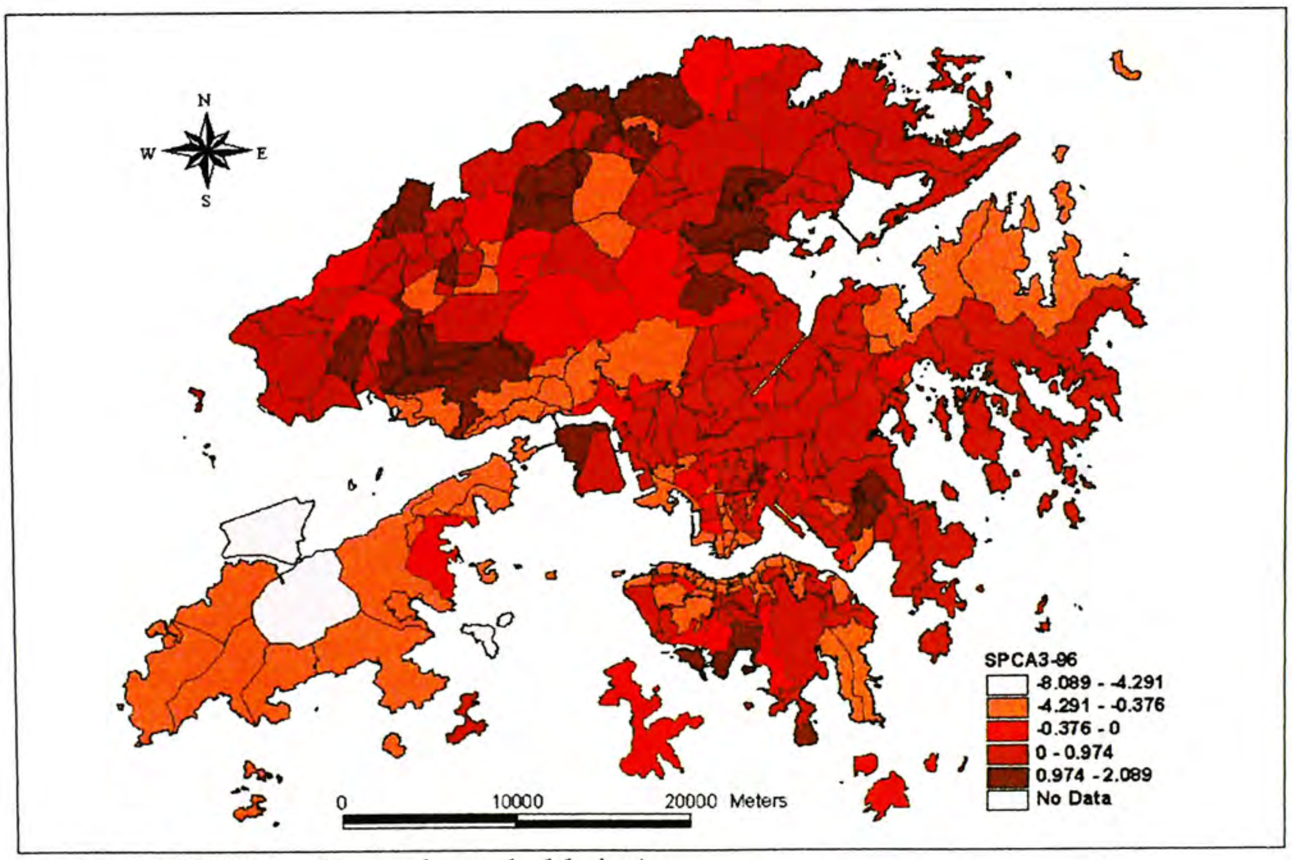

Figure C8 SPCA3$_{96}$ (Large household size)

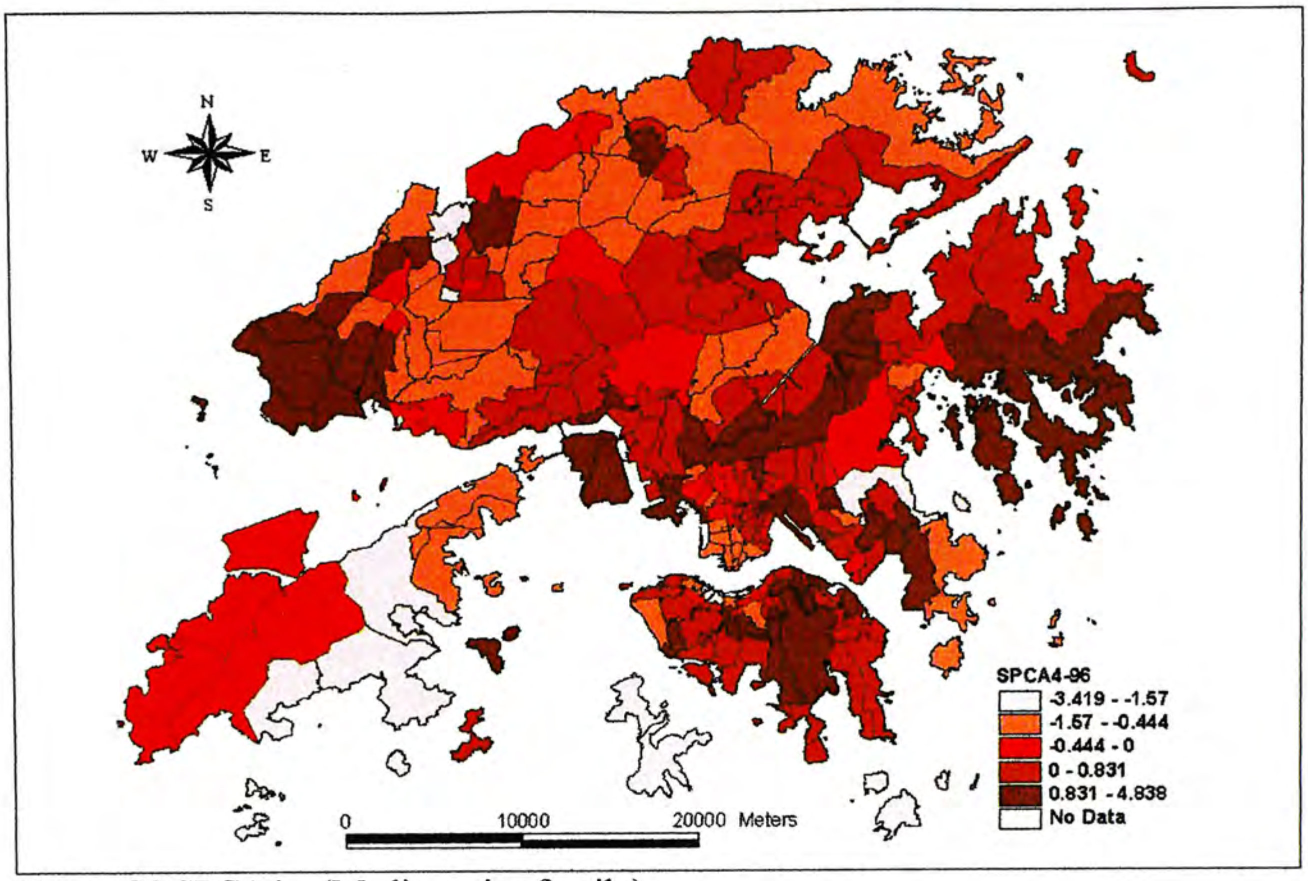

Figure C9 SPCA4$_{96}$ (Medium size family)

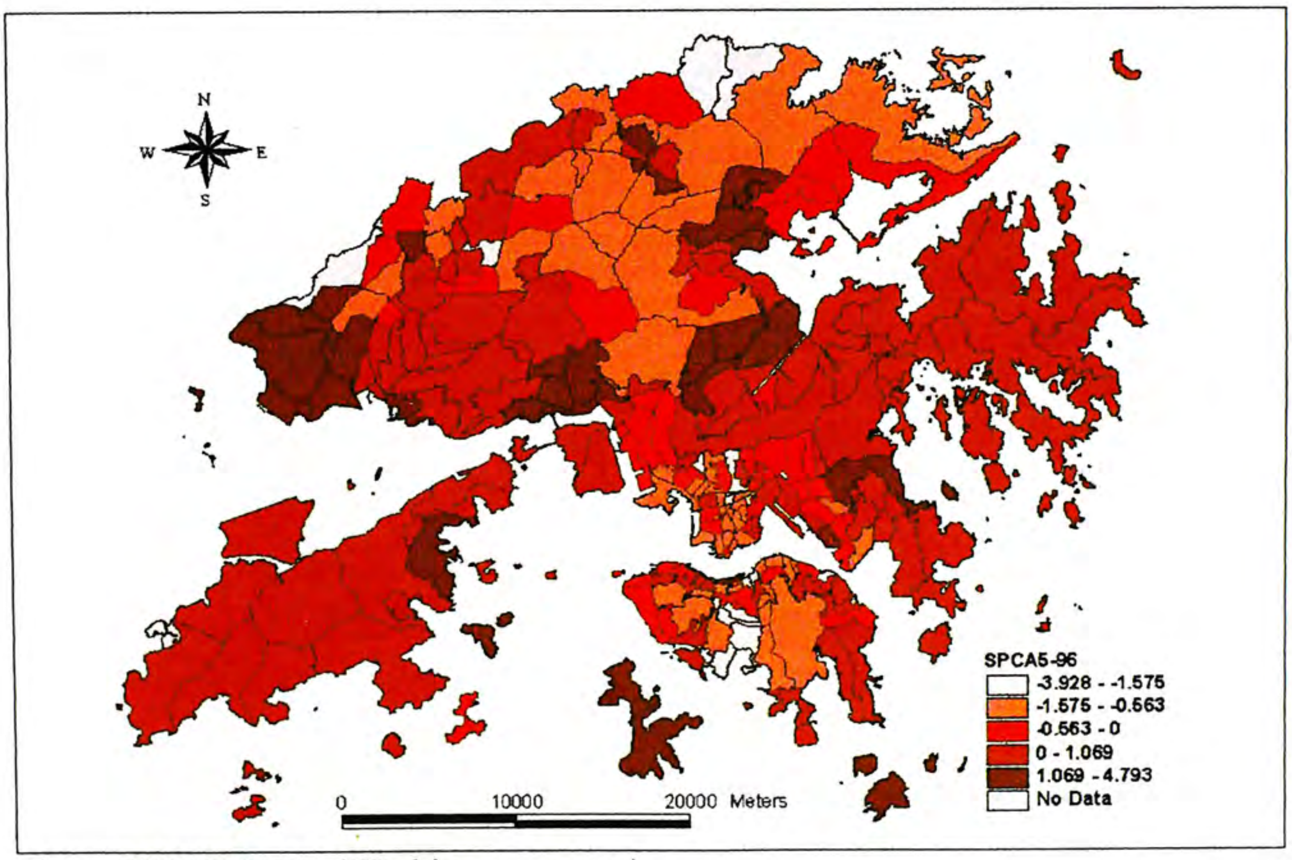

Figure C10 SPCA5$_{96}$ (Working age group)

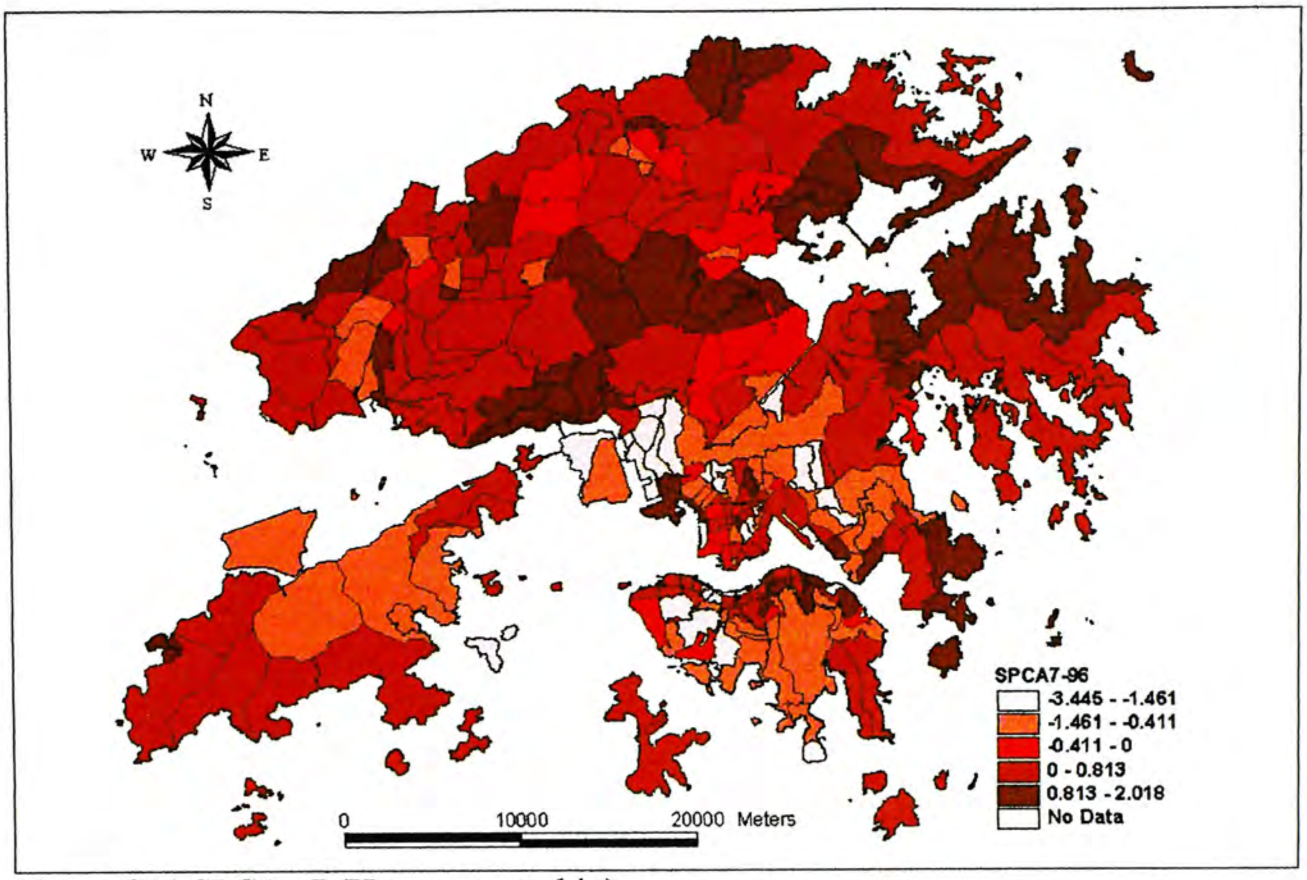

Figure C11 SPCA$_{96}$7 (Home ownership)

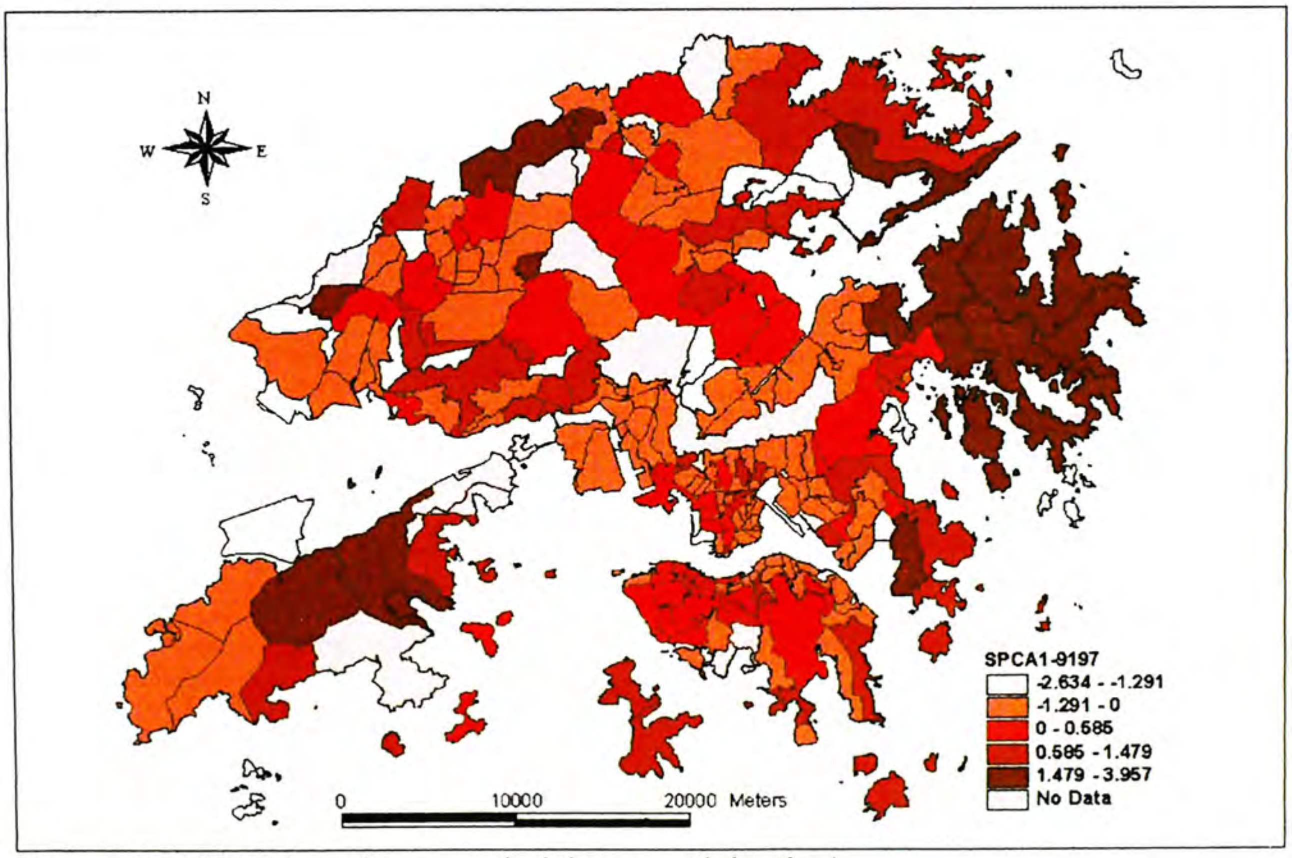

Figure C12 SPCA1$_{9197}$ (Increase in labour participation)

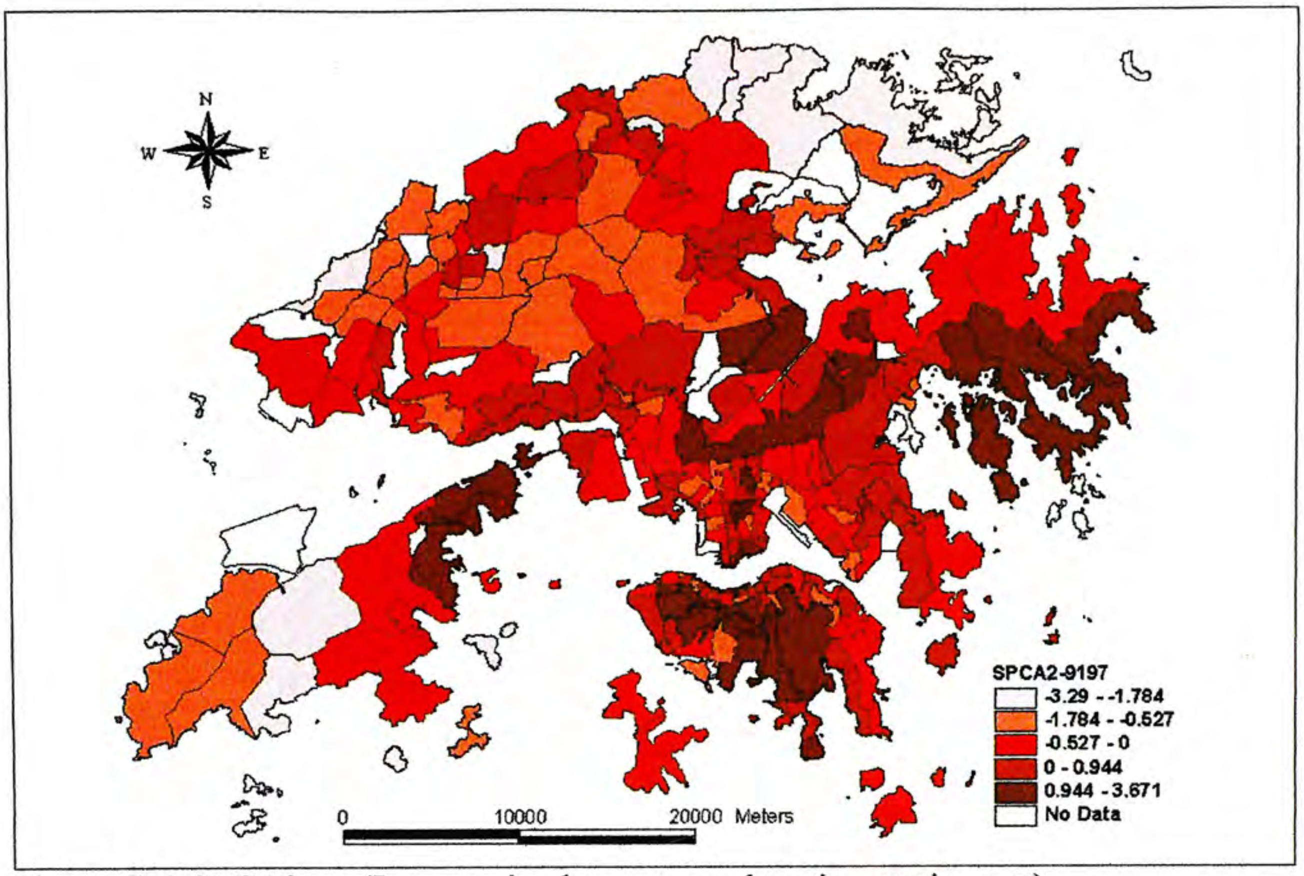

Figure C13 $SPCA2_{9197}$ (Increase in elementary education attainment)

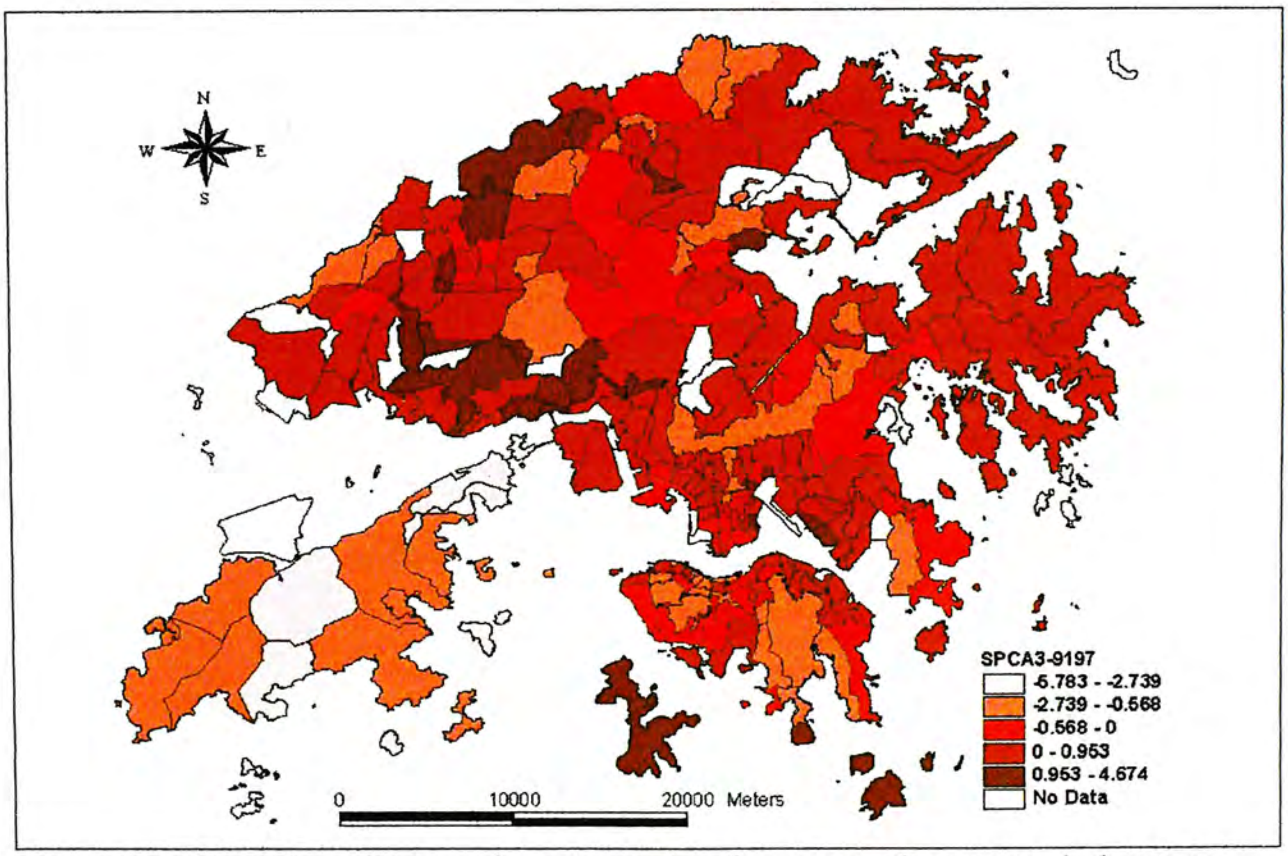

Figure C14 $SPCA3_{9197}$ (Economic restructuring from secondary sector industry to tertiary sector industry)

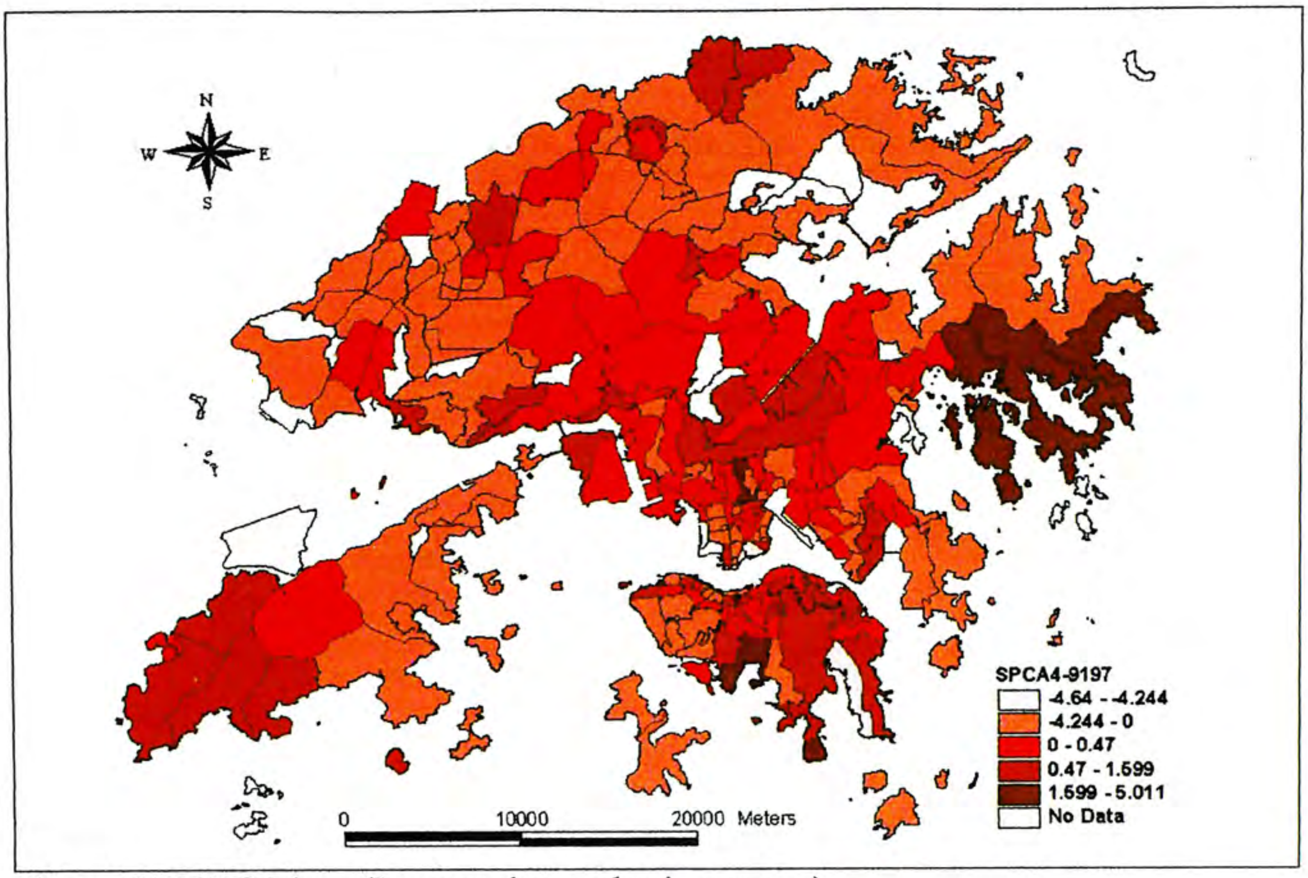

Figure C15 $SPCA4_{9197}$ (Increase in purchasing power)

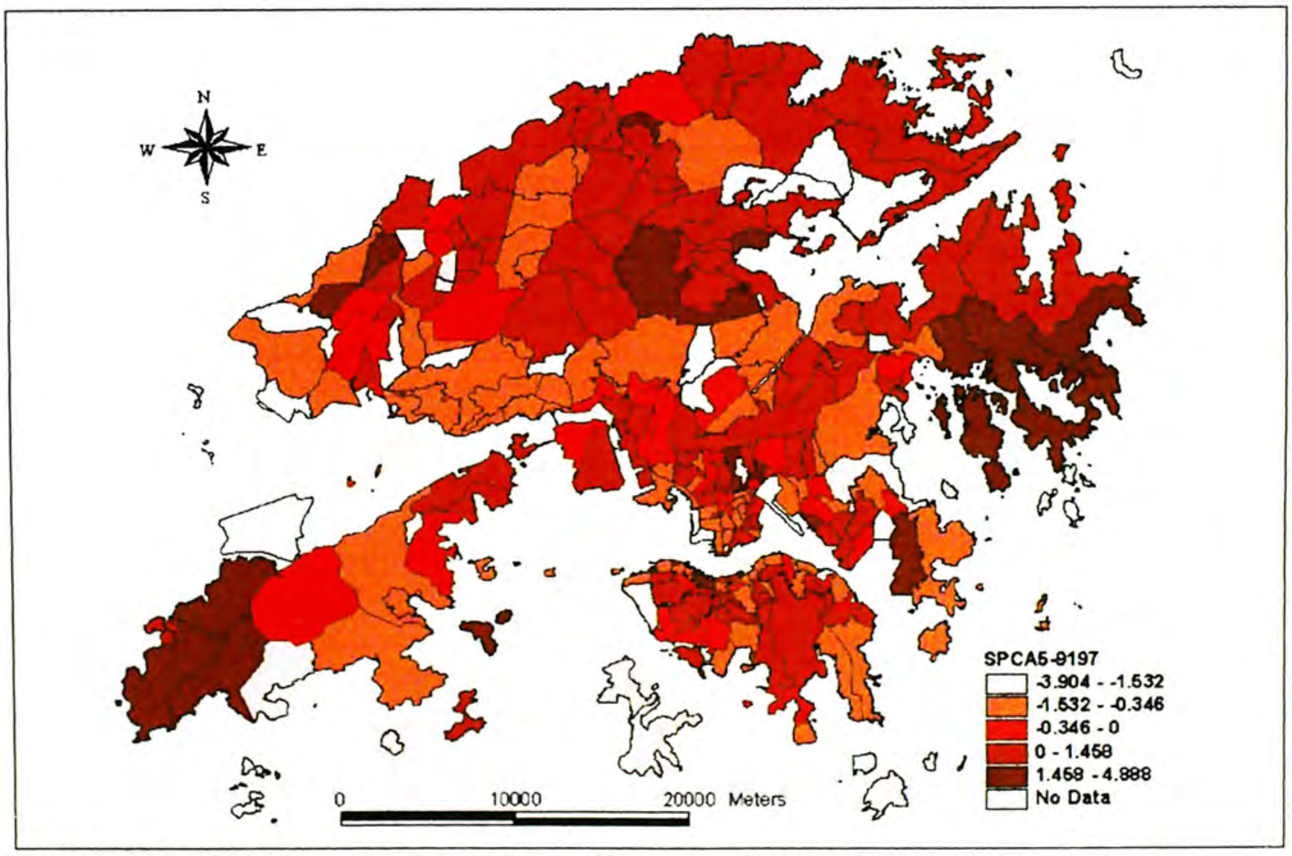

Figure C16 $SPCA5_{9197}$ (Increase in medium size family)

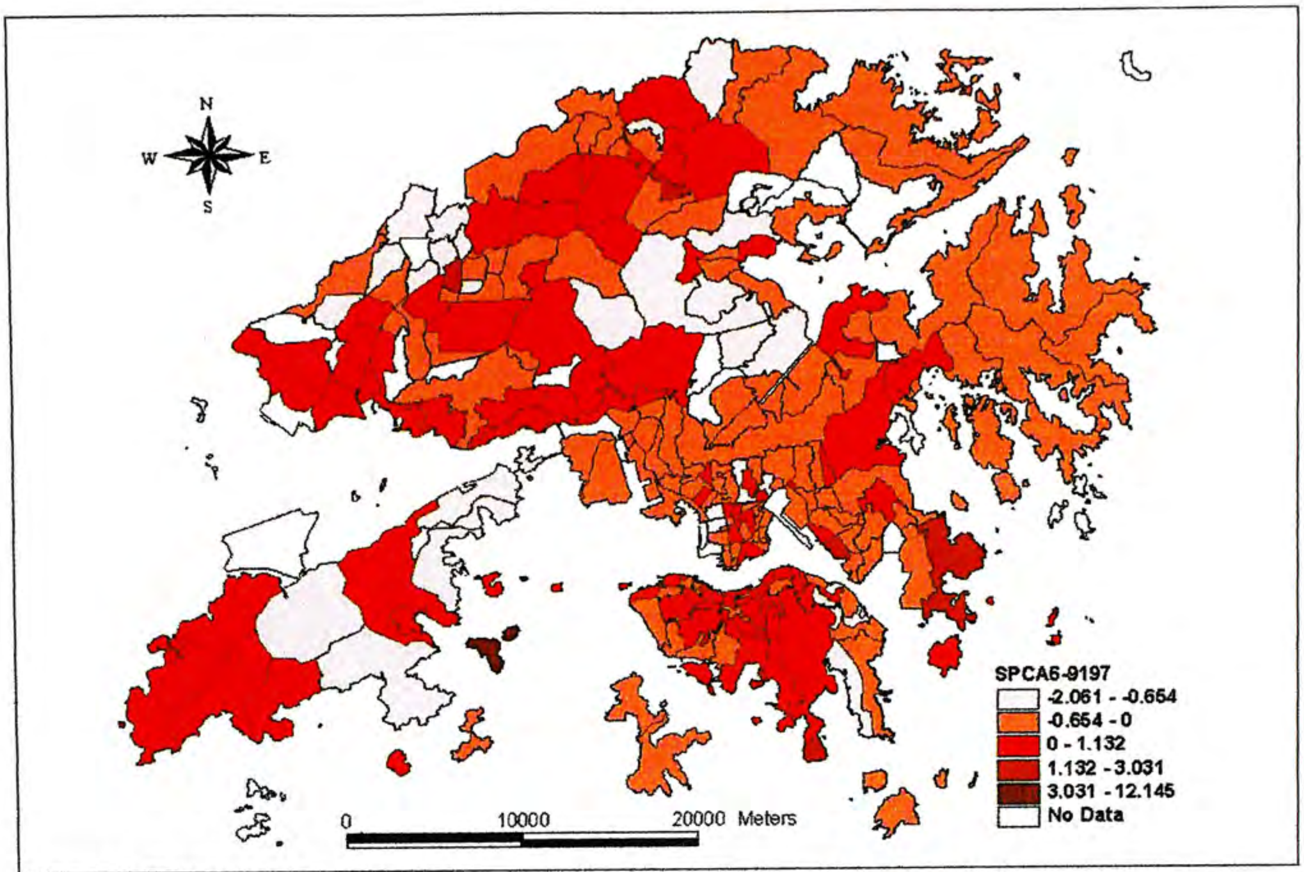

Figure C17 SPCA6$_{9197}$ (Increase in female labour participation rate)

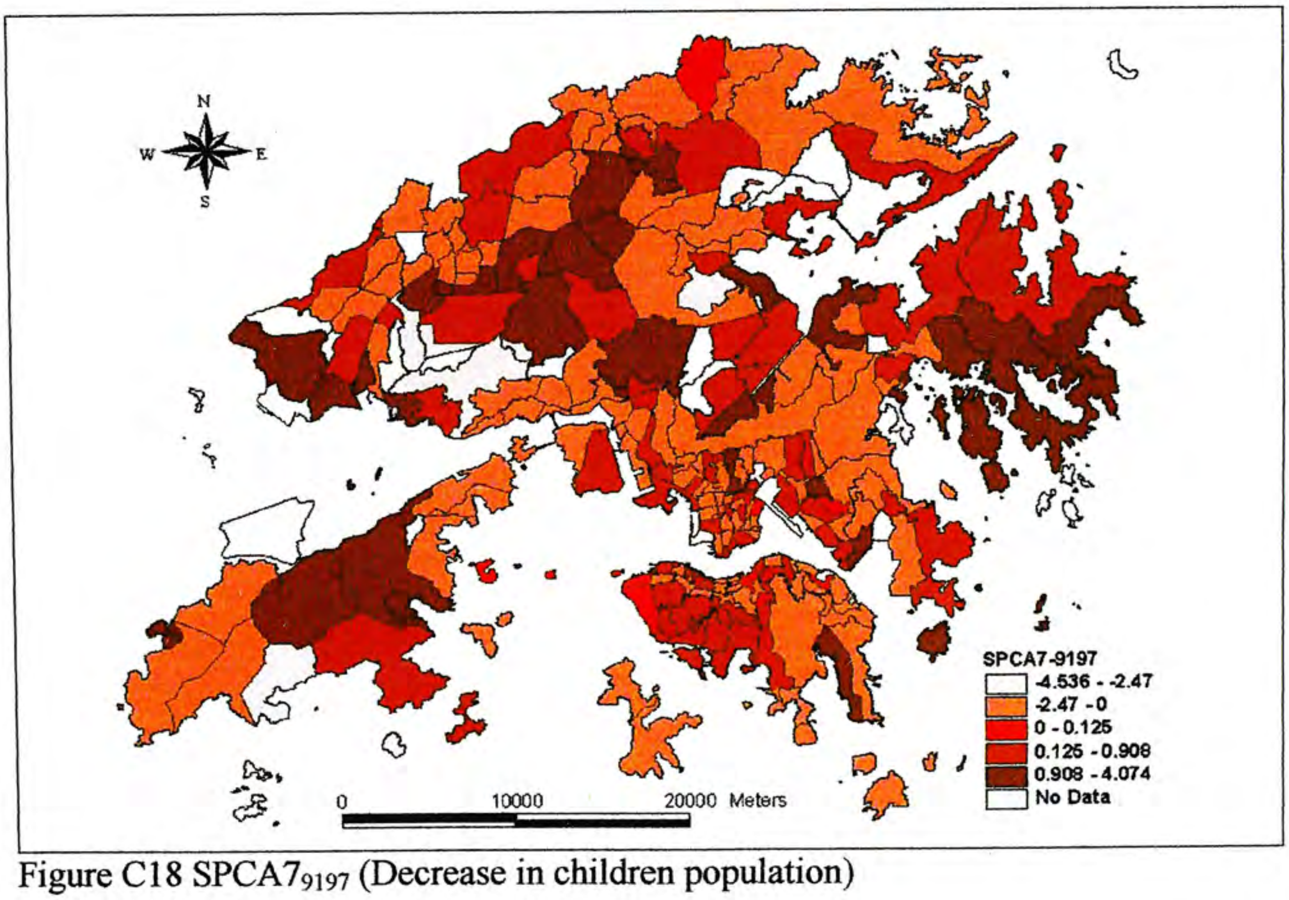

Figure C18 SPCA7$_{9197}$ (Decrease in children population)